

PATTERN AND PROCESS IN CULTURAL EVOLUTION



EDITED BY STEPHEN SHENNAN



PATTERN *and* PROCESS
in CULTURAL EVOLUTION

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ONE

Pattern and Process in Cultural Evolution

AN INTRODUCTION

Stephen Shennan

THE AIM OF THIS book is to demonstrate the potential for building a genuinely integrative evolutionary anthropology, in which evolutionary theory unites studies of the past and the present even though the nature of the evidence often requires different methodologies. A basic premise of the book is that one of the best ways of demonstrating that potential is by means of case studies. It is increasingly clear that, despite the existence of different theoretical schools and positions, such an endeavor does not have to be theoretically exclusive. Evolutionary anthropology is a broad church, not a narrow sect. Not only do supporters of different positions share sufficient common ground that the debates between them can be both theoretically and empirically illuminating even when they disagree, but it is increasingly clear that in many respects the positions are complementary rather than opposed. This was not always the case. The object of this introduction is to explain why the contributors to this book believe that evolutionary concepts can once again provide a coherent core for anthropology as a result of the theoretical developments of the last twenty-five years.

The importance of evolutionary ideas in the disciplines of anthropology and archaeology has varied considerably through time. Social evolution has been the most important strand of thought, conceived initially, following Spencer and Morgan, as charting the trend from Savagery through Barbarism to Civilization, with all the connotations of progress and positive evaluation implied in that last term. In the mid-twentieth century, the dominant figures were Gordon Childe, Leslie White, and Julian Steward. Childe used archaeological evidence to examine how prehistoric societies moved from one evolutionary stage to another. Steward emphasized the importance of tracing particular adaptations through time: multilineal evolution. White focused on what he saw as general evolution: a tendency for social structure on a global scale to become more complex through time as a result of technological innovations that made it possible for humans to extract increasing amounts of energy from the environment, culminating in the development of machines that could make use of fossil fuels, first coal, then oil, which provided the basis for world industrialization. It was such students of Steward and White as Sahlins

and Service who carried forward these now neo-evolutionary ideas into the 1960s and provided the basis for the approach to the archaeological study of prehistoric societies that was adopted by the New Archaeologists and their processual successors.

However, although it is true that such directional concepts of social evolution were largely eclipsed in the anthropology of the first half of the twentieth century, it should not be thought that evolutionary ideas had disappeared. As Lyman and colleagues (Lyman and O'Brien 1997; Lyman, O'Brien, and Dunnell 1997) have pointed out, a different kind of evolutionary idea—that of “descent with modification”—was central to North American culture history, which emphasized the importance of characterizing cultural lineages and of distinguishing similarities between different traditions resulting from common descent from those arising through independent convergent development. Even British social anthropology's timeless functionalism had the evolutionary process of adaptation at its heart.

Neoevolutionist and ecological functionalist concepts of society (e.g., Service 1962; Fried 1967; Harris 1979; Johnson and Earle 1987) were adopted by the New Archaeologists since they seemed to be appropriate for the kinds of evidence that archaeologists have available about past societies. Their sequences of evolutionary stages were based on assuming a trend through time in three different but correlated dimensions: the scale of societies, their degree of differentiation, and the extent to which they are integrated. The more differentiated they are, the more powerful must be the integrative mechanisms that keep them together. The most successful way of doing this is by means of control hierarchies; thus, more complex societies are more hierarchical, and complexity trends are also correlated with increasing social inequality. The reason for the existence of such a trend to complexity was that more complex societies were better at overcoming adaptive challenges, especially those posed by increasing population, whether by feeding more people or by developing greater effectiveness in warfare against

competing groups. Diehl (2000) has referred to this as the general managerial model (GMM). However, as he points out, the worldview represented by the GMM was already very different from the positive evaluation of social evolution as progress found in earlier views. Societies were regarded as being pushed out of the Garden of Eden into complexity and hierarchy, not as inherently wanting to go that way.

This particular version of evolutionism came under attack from proponents of another, Marxism, in the 1970s, but a far more radical attack came from those who argued that the whole idea of the evolution of societies from Savagery to Civilization or simple to complex was a Eurocentric fantasy designed to justify Western domination of a colonial and postcolonial world. This attack represented an aspect of the fragmentation of anthropology that has continued since that time and of the ideology wars of the later 1970s and 1980s. However, just as anthropology was splitting, the evolutionary branch began a process of renewal across a whole range of different fields, largely inspired by developments from outside the discipline.

Most high profile and controversial was the development of human sociobiology, which represented a program for the understanding of variation in human cultural and social institutions—the central goal of anthropology—in terms of their effects on people's survival and reproductive success in different circumstances (e.g., Chagnon and Irons 1979). Its rejection of the rather comfortable ecological functionalism of traditional anthropology on the basis of the critique of group selectionism, and its consequent focus on kin selection and inclusive fitness, not to mention its concern with topics such as male and female reproductive success, made it a very obvious target for attack by the many anthropologists, as well as some leading biologists, who saw it as a combination of biological imperialism and right-wing ideology (e.g., Sahlins 1976; Lewontin, Rose, and Kamin, 1984).

At more or less the same time, Dunnell (1980) was developing the concept of an evolutionary archaeology. He not only rejected neoevolutionism

as a framework for archaeology, arguing that it was descriptive and lacking in explanatory mechanisms, but also denied the possibility of behavioral reconstruction, a key part of the program of processual archaeology, claiming that it was unconvincing and lacked any criteria that could justify its claim to be scientific. The material remains that make up the archaeological record were to be seen, according to Dunnell, as like skeletal remains, an element of the hard part of the human phenotype that had the property of surviving after death, and therefore as analogous to the paleontological fossil record. Artifacts, or attributes of artifacts, either had a function, in which case they would be subject to natural selection, or did not, in which case the only process affecting their frequency over time would be drift (Dunnell 1978).

A third Darwinian approach to cultural phenomena also emerged that was different again. Cavalli-Sforza and Feldman (1973) developed a mathematical framework for cultural evolution by modifying mathematical models from that central pillar of the neo-Darwinian evolutionary synthesis, population genetics, to take into account the different ways in which cultural attributes as opposed to genes are passed on from one person to another. They also showed how these models could be used to understand the changing frequencies of cultural attributes over time. The first full statement of this approach, *Cultural Transmission and Evolution: A Quantitative Approach*, appeared in 1981. This work provided a basis not only for modeling culture in evolutionary terms but also for looking at the relationship between genetic patterns in human populations and cultural ones within a unified framework. It was thus the starting point for so-called dual inheritance or gene-culture coevolution theory.

Since those days, there have been major developments in all these different subfields. Human sociobiology split into two distinct, and to a degree mutually hostile, approaches, evolutionary psychology and human behavioral ecology. The former is concerned with identifying evolved psychological mechanisms in the human

mind that would have emerged as a result of natural selection over the course of biological evolution, and especially in the time since the most recent common ancestor of both chimpanzees and humans, in the so-called environment of evolutionary adaptedness. Because of the enormous difference between adaptive environments then and now, the types of behavior resulting from the operation of those mechanisms may not be adaptive in the present even if they were in the past. The main way to identify the mechanisms is by carrying out psychological experiments. Evolutionary psychology has become a major area of research and academic activity with a high public profile. The Human Behavior and Evolution Society was founded in 1988 with a focus largely on evolutionary psychology, and the same was true of its journal, *Evolution and Human Behavior*, although both have broadened their evolutionary interests in recent years.

Human behavioral ecology, on the other hand, postulates that people are behaviorally plastic, in the context of general dispositions towards courses of action that tend to lead to improved survival and reproductive success, and of an ability to perceive and react appropriately to relevant environmental cues; these perceptions and reactions may be conscious or unconscious. Accordingly, people should tend to act in optimizing ways to the various challenges posed by their local adaptive environment, even if that is a novel one. The way to investigate this is by naturalistic studies that identify the adaptive constraints and opportunities that characterize particular situations and then collect data to test whether people are indeed acting optimally. This can be done by means of ethnography, observing and measuring what people actually do, in which case it runs the risk that the evidence for adaptive processes may be overwhelmed by contingencies and “noise” over the short time frame that such ethnographic investigations are usually carried out; or by means of archaeology—for example, looking at subsistence trends evident in food residues resulting from multiple episodes of hunting over a long period of time, in which case it may be difficult to identify the adaptive

opportunities and constraints that actually existed, never mind overcome the usual exigencies of the archaeological record. Nevertheless, in the specific form of optimal foraging theory, human behavioral ecology has become a widely used framework for the empirical study of subsistence systems, both archaeologically and ethnographically (see, e.g., Winterhalder and Smith 2000; Bird and O'Connell 2006). A landmark publication in the field of human behavioral ecology was Smith and Winterhalder's edited *Evolutionary Ecology and Human Behavior* (1992), which demonstrated the potential of using human behavioral ecology theory to explain variation not only in subsistence practices but also in time allocation, collective action, competition, and conflict and population dynamics, among other topics. Their subsequent review of the field in its first twenty-five years (Winterhalder and Smith 2000) showed that its case studies in anthropology by then covered a wide range of topics, especially reproduction, but that in archaeology they were still largely restricted to studies of production. However, the authors point out (2000, 67), despite its demonstrable achievements, human behavioral ecology "remains a modest and marginalized enterprise in contemporary anthropology," a situation that is still only slowly changing.

In evolutionary psychology and human behavioral ecology, the motor for acting in ways that are appropriate in evolutionary terms comes from a combination of psychological mechanisms and environmental stimuli. Behavioral plasticity makes it possible for people to modify what they do in adaptively appropriate ways. What both have in common is that they attach very little importance to culture and to the impact of cultural transmission on what people do. In this respect, they differ fundamentally from both evolutionary archaeology and dual inheritance theory. The differences between evolutionary archaeology and HBE are spelled out most clearly in the debate between Lyman and O'Brien (1998), on the one hand, and Boone and Smith (1998), on the other, in the pages of *Current Anthropology* in the late 1990s; these

differences revolve around the role of transmission and selection. For Boone and Smith, the process by which Cree Indians gave up using snowshoes for snowmobiles was nothing to do with natural selection—it did not take place as a result of the snowmobile users becoming more reproductively successful than continuing users of snowshoes and outcompeting them as a result—and everything to do with behaviorally plastic decision making underpinned by selection-influenced capacities. For O'Brien and Lyman, the demise of the snowshoe, an artifact type with a long history conditioned by its functional requirements (i.e., subject to selection), and its replacement by the snowmobile, a different artifact with essentially a shorter but more complex history of transmission, could indeed be seen as a Darwinian process in the strictest terms, although that process need not be related to the survival or otherwise of the population of users. Clearly both are right—the difference is one of perspective—but for an archaeologist with information about chronological sequences of changing artifacts, the O'Brien and Lyman approach arguably makes more sense. Since within evolutionary archaeology the most important task is to distinguish functional from stylistic variation, or variation under selection from that subject solely to drift, a great deal of attention was given to this task (e.g., O'Brien et al. 1994). In this respect, the key achievement was Neiman's (1995) demonstration of the way the mathematics of the neutral theory of evolution (Kimura 1983) could be used to generate quantitative expectations of what a sequence of artifact frequencies should look like if drift is the only factor affecting it.

Since the early 1980s, the main developers of dual inheritance theory, concerned with the implications of the idea that humans are characterized by two inheritance systems, genetic and cultural, have been Boyd and Richerson and their former students (1985; Richerson and Boyd 2005; numerous other publications). They have continued the strongly mathematical modeling line started by Cavalli-Sforza and Feldman. However, whereas the latter assumed

the existence of cultural transmission, Boyd and Richerson went a step further back and proposed models to explain the cognition involved in learning, including the factors that select for cultural learning. A key aim of this work has been to show that cultural transmission cannot be neglected if we are to look at human culture and behavior through an evolutionary lens, since without taking it into account we arrive at invalid conclusions. The existence of the exceptional levels of cooperation that characterize the human species, for example, cannot be understood without the process of cultural group selection (e.g., Henrich 2004). A particular feature of the work in this tradition has been the detailed mathematical characterization of the variety of mechanisms that affect what is transmitted through time and the consequences they have. Given the complexities involved, it is worth spelling out these mechanisms since failure to distinguish among them is often a source of serious confusion.

Natural selection in the narrowest sense affects humans as it does members of all other species; for example, other things being equal, individuals whose genes give them more resistance to diseases in childhood are more likely to survive and reproduce than those who do not have that resistance, and those genes will be more widely represented in future generations. However, natural selection can also act on cultural attributes, in the sense that those individuals who possess certain cultural attributes may have a greater probability of surviving and reproducing than those who do not, a process that will continue so long as those possessing the cultural attributes pass them on to their children and the selective environment does not change; as a result, those cultural attributes will become increasingly prevalent. For example, it is clear that in many parts of the world, adopting an agricultural rather than a hunting-and-gathering way of life led to greater reproductive success because population densities increased considerably; the cultural traits that characterize agriculture spread as a result. An analogous process of *cultural* selection can also operate if

individuals with certain cultural traits are more likely to be taken as models for imitation than others by virtue of those traits, and these in turn become successful models as a result. The traits concerned will become more prevalent even if they have no bearing on reproductive success whatsoever and, indeed, even if they are deleterious to it. This is because if an attribute is passed on other than by parents to children, there is no reason for its success to depend on the reproductive success of the individuals concerned.

However, in addition to these processes of selection, Boyd and Richerson proposed a series of other processes that could affect what was transmitted. “Guided variation” recognizes the capacity that individuals have for experimenting with what they do and discovering new ways of doing things, which may lead them to abandon what they learned as children. Their “bias” processes refer to factors that affect what and who people try to copy when they are learning from others. Thus, “content (or direct) bias” refers to the situation where people look at what other people do—for example, the crops they plant—compare the results with what they are doing themselves, and then change what they do because the other way of doing things seems to be more effective. In other words, it is a recognition of the content of the practice that leads to change. Other examples of content biases are fairy tales or so-called urban myths, which appear to be intrinsically memorable for reasons relating to the structure of the mind or the strong reactions they provoke. But this is not the only factor affecting what people copy or what practices they decide to adopt: something may be copied simply because the person initially doing it is prestigious (“prestige [or indirect] bias”) or because it is what most people locally do (“conformist [or positive frequency-dependent] bias”). In these latter two cases, whether a particular cultural attribute or practice becomes more prevalent in a population has nothing to do with its intrinsic properties but only with the nature of the copying and its source.

All the different processes just described are focused on the human decision makers, but it is

also worth asking what they look like from the point of the cultural attributes or practices themselves—their prevalence over time and the modifications that occur in them. This question is of particular interest to archaeologists, who can trace histories of cultural features over time but do not have direct observational access to people's decision making. This, of course, is what evolutionary archaeology was concerned to understand, but it only distinguished natural selection and drift; the dual inheritance approach makes it clear that things are a great deal more complex and that many more distinctions need to be made. Whether it is possible to make them in any given archaeological case is another matter, but the basic procedure is clear. It is necessary to identify histories of transmission, to show that an ancestor–descendant relationship exists, if indeed it does (O'Brien and Lyman 2000), and then attempt to understand the forces shaping it. Thus, Bettinger and Eerkens's (1999) analysis of variation in arrow points in the western United States proposed that in central Nevada they were adopted by a process of prestige bias without any examination of the functional efficacy of their different attributes, whereas in eastern California there was experimentation with the different attributes, which led to greater variation and more independence between them. In effect, “evolutionary archaeology” has to be seen as an artifact-focused subset of the dual inheritance approach that has to take into account all the latter's various processes, such as conformist and prestige bias. Moreover, its “natural selection” or “functional” category has to further distinguish between those artifacts or attributes that are prevalent as a result of giving a selective advantage to members of the biological population in survival or reproductive terms and those that are successful as a result of “content bias”—people see them and adopt them because they are more effective in some way. In the famous example discussed earlier, snowmobiles became more prevalent as a result of content (direct) bias, not natural selection. Indeed, making this distinction is at the root of some of the most long-standing debates in

archaeology. For example, was the spread of farming into Europe a process of indigenous adoption (content bias) or demographic expansion and extinction (natural selection)?

All these distinctions clearly make the understanding of what is going on in cultural evolution very complex, and a great deal of the effort of the dual inheritance approach has been on modeling processes and their outcomes in general terms rather than trying to understand specific cases. This is, after all, one of the main tasks of social science, although it is not very congenial to the current widely prevalent cultural particularism. Moreover, despite the best efforts of its practitioners to explain their ideas clearly in words, the heavily mathematical formulations of dual inheritance theory have made it more congenial to disciplines such as economics rather than anthropology or archaeology. In combination with the allergic reaction that many anthropologists have to linking Darwinian processes to people, this has resulted in the dual inheritance approach remaining a minority interest despite its close parallels to approaches such as practice theory that they find more attractive (Shennan 1989). It is significant and unsurprising that within anthropology in the broad sense it is biological anthropology that has taken the strongest interest in modern cultural evolution. This is clearly evident in the journal *Evolutionary Anthropology*, set up in the 1990s, which covers everything from primate fossils to theoretical studies of cultural evolutionary processes.

Despite the disputes between proponents of the different evolutionary perspectives, it is becoming increasingly clear that in many respects the positions are complementary rather than opposed. This is apparent in many ways. The neutral modeling of archaeological data developed by Neiman (1995) in the context of evolutionary archaeology has been incorporated into a dual inheritance approach by a number of authors in studies that have identified both conformist and anticonformist transmission (Kohler, Vanbuskirk, and Ruscavage-Barz 2004; Shennan and Wilkinson 2001). The set of transmission biases initially

identified by Boyd and Richerson is being enlarged and becoming more complex. It is being increasingly recognized, for example, that it is necessary to gain a greater understanding of the psychology of transmission, and this requirement is leading advocates of dual inheritance theory to carry out psychological experiments (e.g., McElreath et al. 2005; Mesoudi and O'Brien, this volume). Many advocates of human behavioral ecology have accepted that identifying whether a particular feature present in a number of societies can be explained as an adaptation involves considering the possibility that its presence is due to the fact that those societies are descended from a common ancestor. In other words, the study of adaptive behavior cannot be separated from the study of inheritance (e.g., Mace and Pagel 1994; Fortunato and Mace, this volume). Furthermore, different approaches can be used tactically, in relation to specific problems, without implying an exclusive commitment to a particular theoretical school.

A further recent theoretical development has been the building of increasingly rigorous approaches to the process of "niche construction" and so-called ecological inheritance (Odling-Smee, Laland, and Feldman 2003). This is the idea that, in addition to genetic and cultural inheritance mechanisms, there is a third one: the transmission of selective environments. All living creatures modify their environments and in doing so change the selective conditions for their descendants, thus having a feedback effect on gene frequencies. In the cases of humans and some other species where cultural inheritance is significant, there will be a feedback to cultural attributes as well. Thus, for example, the change in human environments created by the growth of cities may have had an effect on gene frequencies as a result of increasing the incidence of epidemic disease, while the existence of the buildings themselves would have informed ideas about appropriate architectural form just as much if not more than any specific instruction or teaching that the builders might have received.

In this spirit of nonexclusiveness, the chapters in this book take a broad view of current

achievements in building an empirically based evolutionary archaeology and anthropology by examining three broad interrelated themes: cultural transmission; the testing of evolutionary, especially adaptive, hypotheses; and social evolution. They do so in the belief that evolutionary theory can provide a unifying framework for anthropology that has long been lacking, but also that the application of evolutionary theory to human cultures and societies will only be taken seriously if it offers productive new approaches that can ultimately lead to answering long-standing questions.

UNDERSTANDING CULTURAL TRANSMISSION

As we have seen already, the first theme involves taking culture as a system of "descent with modification" in which what is inherited from previous generations is modified by a variety of processes. Without a process of cultural inheritance there can be no evolutionary theory of culture, only a theory that explains what people do in terms of evolved psychological mechanisms and behavioral plasticity. Unsurprisingly, therefore, the chapters in this section draw heavily on dual inheritance theory.

The chapter by Mesoudi and O'Brien takes the arguments of this introduction further by examining how archaeology fits into a general evolutionary framework for the understanding of culture and proposes that it should be seen largely as a means of approaching macroevolutionary patterns—for example, through the use of phylogenetic methods to reconstruct artifact lineages and their relationships. Nevertheless, such studies cannot be undertaken in isolation. The patterns cannot be explained without taking into account what we know about the microevolutionary processes of cultural transmission, and our understanding of these has to be taken forward in a variety of ways, including the use of both psychological experiments and computer modeling. A key aspect of the evolutionary framework is that it is synthetic, so that work in one area can provide a basis for progress in another.

Aunger's chapter is in a sense even more ambitious since it proposes placing cultural transmission in a broader context. Rejecting existing accounts of transmission mechanisms because they do not provide an adequate account of human communication, Aunger argues that a valid account of the process of communication leads to the conclusion that it should be seen as "an instance of niche construction using signs, signals, or artifacts that is targeted at changing the behavior of conspecifics." While this perspective does not include what Aunger refers to as unintentional or inadvertent transmission, which he acknowledges as important, it has significant implications. It brings the process of intentional transmission within the more general orbit of signaling theory and its concern not just with the transmission and reception of signals but with their effects on behavior and their relation to the strategic goals of agents. It also treats the process of communication as one of niche construction in that communication activities always involve modifications of the local environment. These may be short-lived—for example, words or gestures—but they can also take a more long-lasting form, such as the production of books or the construction of monuments. The desired effect of such constructions is to modify individuals' minds and as a consequence to alter their behavior in ways favorable to the fitness of the communicator.

Hosfield's chapter takes up an aspect of the evolutionary agenda of Mesoudi and O'Brien in examining the microscale processes involved in a specific field of transmission of great importance to archaeologists, that concerned with craft skills. An extensive survey of the ethnographic literature is used to examine the relation between vertical and horizontal modes of transmission and a variety of other variables, and rates of change in the resulting material culture. Hosfield shows that while vertical transmission tends to be associated with conservatism and horizontal transmission with innovation, this is not the whole story. He goes on to consider the implications that his findings have for studies of the archaeological record, suggesting ways in

which degrees of horizontal transmission could be measured archaeologically while avoiding the danger of circular argument.

Jordan uses the exceptional ethnographic data obtained from his work on the Khanty communities of the Lower Ob' River in northwest Siberia to carry out a quantitative analysis of material culture diversity using the NeighborNet program for the analysis of phylogenetic networks. His results indicate that female and male clothing features had different descent histories, the former reflecting individual identity and the creative recombination of a variety of different traits, the latter suggesting a stronger signal of vertical transmission and branching descent. Thanks to the availability of extensive historical and ethnographic information, he is able to relate the results to patterns of subsistence, kinship, and mobility. Thus, cultural hybridization seems to have been connected to increasing population and the growth of reindeer pastoralism and commercial fishing in response to increasing colonial Russian impacts, but there also seems to be an important cultural and linguistic frontier related to the alignment of marriage contacts. As Jordan points out, one spin-off from this sort of work is the identification of factors that can be built into simulation models that explore systematically the way variables interact to produce cultural diversity.

Riede, too, takes up the issue of tracing lineages of cultural transmission but specifically focusing on the extent to which "cultural packages" exist—sets of attributes that have similar histories and therefore similar patterns of descent. If they do then they should have similar phylogenetic trees. Using tree reconciliation methods that have been developed to explore the relationships between the phylogenies of parasites and their hosts, Riede illustrates the possibilities of identifying cultural association by descent and presents an example analyzing the linkage between the trees of knives and forks in early cutlery sets. Clearly this is a case where we would expect the trees to be closely matched, but the potential for looking at more complex cases is clear. Of course, it is not being

claimed that the processes producing cospeciation in hosts and parasites and those producing patterns of branching change in knives and forks that correspond to one another are exactly the same. Instead, the different processes simply will produce similar patterns that justify the application of a method designed to assess the strength of those patterns.

Tehrani and Collard explore similar issues with their analysis of the evolution of material culture diversity among tribal populations in Iran on the basis of a cladistic analysis of variation in woven textiles between different tribal groups. They show that a clear majority of the resemblances among the textile assemblages could be accounted for by the branching pattern of descent represented by the cladogram, which was also strongly supported by a bootstrap analysis. In fact, the proportion of resemblances among the textile assemblages that could be accounted for by inheritance from ancestral taxa corresponded to the average for cladistic analyses of groups of biological species. However, a comparison of the textile cladogram with the pattern of linguistic relationships among the groups concerned showed agreement in some cases but not in others, which points to the role of horizontal transmission across linguistic boundaries as well as inheritance from ancestral populations. In other words, the distribution of different weaving traditions among Iranian groups should be seen in terms of a “multiple packages” model of culture (Boyd et al. 1997), not one in which there are strong and dominant general “core traditions.”

Cochrane offers his own take on the relationship between the evolutionary archaeology and dual inheritance approaches and their relative usefulness in terms of explaining variation in the archaeological record. He does so by means of a comparison between two other evolutionary disciplines, paleontology and evolutionary biology, whose relationship arguably parallels that between evolutionary archaeology and the dual inheritance approach. He further explores the issues by means of a case study from his work on ceramic change in Fiji which uses seriation and

cladistics to identify transmission lineages. Once these have been characterized, an analysis of vessel thickness is carried out, taking a drift model of variation in a continuous trait developed by Eerkens and Lipo (2005) as a null hypothesis. After showing that the drift model must be rejected, Cochrane discusses the possible role of a variety of alternative models of transmission bias from dual inheritance theory before concluding that it is not always going to be possible to test among such alternatives using data from the archaeological record.

The final chapter in this section also examines ways in which transmission lineages can be characterized and the forces acting on them identified, but in this case looking at iron production. This is much more difficult than in the case of, for example, pottery, where there is a great deal of room for variation in many different features without compromising its practical utility: iron production is characterized by strong engineering and geological constraints. Charlton pursues the problem through an analysis of the slag produced during production, which contains a record, albeit complex and difficult to read, of the recipe used in the process of which it is a by-product. He shows how multivariate analysis of slag chemistry can indeed provide information not just on technological lineages of iron production but also on the factors that may have affected them, through a study of material from three bloomery iron production sites in northwest Wales.

TESTING EVOLUTIONARY HYPOTHESES

The chapters in the second part of the book move away from issues connected with the nature of transmission and the construction of transmission lineages to focus on a different set of problems: those that arise in testing evolutionary hypotheses, and particularly in trying to assess the importance of adaptation in accounting for cultural patterns. They demonstrate that no particular recipe exists for doing this but that it involves the use of a rather eclectic mix of methods and ideas.

Lake and Venti's chapter takes its inspiration from studies of macroevolution on the broadest scale, not from the dual inheritance ideas so central to most of the chapters in the previous section, and introduces concepts from a different evolutionary tradition that emphasizes the role of self-organizing processes. There is a well-established pattern in biological evolution of early differentiation across higher taxa (adaptive radiation or breadth-first search) followed by contraction, in which many of the early taxa disappear and only a few persist. Kauffman (1995) has suggested that this pattern can be understood if we imagine that evolution takes place on a moderately rugged "fitness landscape," in which peaks represent points of high fitness and valleys indicate troughs of low fitness that have to be crossed if new peaks of higher fitness are to be reached. An adaptive radiation represents an early phase in an evolutionary process in which long-distance jumps to empty peaks in the fitness landscape can be successful. Kauffman went on to suggest that technological evolution occurs in a similar fashion. Lake and Venti follow others in addressing the evolution of the bicycle from this perspective, but in a much more rigorous fashion, by creating a new set of bicycle taxonomies that incorporates the macroevolutionary concept of "generative entrenchment," the idea that once certain basic features of an organism or a technology come into existence, they strongly determine other features. The results support the conclusion that in the case of the evolution of the bicycle, a process of breadth-first search is followed by a contraction, commensurate with the expectation that expansion most readily occurs in empty ecological spaces and that contraction occurs as the ecological space is populated and competition intensifies. Minetti, Pinkerton, and Zamparo (2001) argue that speed and efficiency provided the primary selective pressure that winnowed out the initial variation, in the context of the mechanical strengths and weaknesses of the human body.

Steele addresses a key issue in distinguishing different evolutionary processes from one another by examining the contrasting assump-

tions of human behavioral ecology and of dual inheritance theory in the context of their different approaches to innovation diffusion. He uses two classic case studies of innovation diffusion as his examples: the spread of hybrid corn and that of the tractor in the United States. As Steele explains, human behavioral ecologists would expect adoption of an innovation to be contingent on a fitness advantage that adopters would gain, while dual inheritance theorists would expect adoption rates to be determined by the status and success, as well as by the number, of prior adopters. It has been argued that the two processes can be distinguished by the shape of the adoption curve, with an S-shaped cumulative adoption curve indicating indirectly biased transmission or social contagion and thus consonant with the predictions of dual inheritance theory rather than human behavioral ecology. However, Steele shows that this is only true where the population is homogeneous with regard to price and utility thresholds for innovation adoption. Where there is heterogeneity, variations in the adoption threshold can produce exactly the same curves without any contagion or transmission process. He goes on to look at the case of spatial traveling waves of adoption and finds that the same problem arises. In other words, spatial and chronological patterns in innovation adoption are not sufficient on their own to distinguish between these processes; to do so requires further information about individual and environmental variation.

Despite the very different context and problem, Smith and his coauthors in the following chapter address a related set of issues. One of the longest-standing patterns recognized in Lower Paleolithic archaeology is the existence of the so-called Movius line, a boundary between those more easterly parts of the Old World where handaxes and Levallois flakes are absent, and the western parts (western Eurasia and Africa) where they are present. A variety of explanations have been offered to account for it. Smith and his colleagues use a simulation model for hominin dispersal and cultural transmission to try to explain the existence of the

Movius line and the relatively late appearance of the Acheulean in Europe as compared with Africa. The model is a deliberately simple one in which, from a starting point in East Africa, populations colonize adjacent squares on a coarse grid on the basis of a series of rules concerning colonization, competition and the probability of extinction that are affected by factors such as vegetation, climate, and proximity to the coast. The population in each square is characterized by distributions of cultural trait frequencies that are affected by drift and mixing, involving cultural transmission between adjacent squares, but the model does not include any element of selection. The results show that models using extremely basic parameters relating to the effect of geographic and paleoenvironmental patterns on dispersal and transmission processes can successfully reproduce the known global patterning in Lower Paleolithic lithic technology. The study provides a classic example of the way in which our knowledge of microscale processes can provide a foundation for models that can operate productively on the broadest spatial and temporal scales.

Edinburgh's chapter also addresses the factors accounting for variation in lithic assemblages—in his case, changes in projectile point technology in the Mesolithic of northern Europe on the basis of data from seven southern Scandinavian sites dating from 6600 to 5400 BCE. He demonstrates that a long period of stability in the use of an indirect percussion technology and obliquely hafted points was succeeded in a short space of time by a change to transverse arrowheads produced by direct percussion. The possibility that the technological changes could be accounted for as a result of changing prey priorities was tested by carrying out a correspondence analysis of osteological data that suggested that prey types remained constant while arrowheads varied in shape and complexity. To test an alternative hypothesis—that the changes in arrowhead technology relate to changes in the local population—a regional-level model of relative population levels was constructed, using summed probability distributions of radiometric

data as a proxy. Since arrowhead complexity was lost and point shape changed at a time when the population level was seen to drop dramatically before increasing again, the results support a population-related mechanism as an explanation for the changes in the case study data.

The last chapter in this section, by Fitzhugh and Trusler, follows up Fitzhugh's earlier work on the relation between innovation and risk sensitivity. An illuminating initial discussion of the factors affecting innovation leads to a specific archaeological study that addresses the issue of how these may be identified in the archaeological record. Specifically, it asks why the inhabitants of Fitzhugh's Tanginak Spring site in the Aleutian Islands initially emphasized core and blade technology in their lithic production but later switched to a bifacial technology. Indeed, can this really be regarded as an innovation? Eventually, and reluctantly, the authors conclude that they have to turn to an adaptive model centered on the risks of technological failure in hunter-gatherer food-gathering technology and the advantages of reliable as opposed to maintainable tools (Bleed 1986; Torrence 1989). As populations increased and territories decreased in size, people spent more time at specific campsites and had the time to invest in reliable bifacial tools, which were becoming increasingly important as a result of climatic cooling that had the effect of cutting available foraging time. This widespread climatic pattern, as well as networks of maritime contact, made the shift to bifacial technology very widespread in the region.

SOCIAL EVOLUTION

The last section of the book addresses the theme of social evolution, once unquestioned, now controversial. As pointed out earlier, from the nineteenth century onward, the Spencerian characterization of social evolution as representing a global trend from Savagery to Barbarism to Civilization, or from Band through Tribe and Chiefdom to State, has been the predominant evolutionary strand in anthropology. Despite the postmodern critique, the patterns behind the

long-standing belief in the existence of long-term trends in society cannot be ignored, for reasons explained by Trigger (1998). Readings of world history may have been far too teleological and value laden in the past, but the refusal to recognize that some societies in the present and the past have been far more powerful than others and have been able to exercise that power to the severe detriment of large parts of the world represents a blindness to reality. This point does not mean that the rise of large-scale, powerful hierarchical societies is the only story of interest, but it does mean that it cannot be ignored. However, we do not need to continue trying to infer process from static typological schemes in the present. The way to pursue these issues is through a different sort of comparative approach from traditional social typology, one that attempts to explain the similarities and differences between local trajectories of change in specific historical contexts (cf. Diamond 1997).

For many reasons, such studies should be carried out within a Darwinian framework rather than any other. For example, as noted already, to establish whether particular social features co-occur in different societies because of some sort of cause-and-effect or feedback relation between them, we also need to consider the possibility that they do so simply because the two societies are descended from a common ancestor.

However, the shift to a Darwinian framework for the understanding of social change, and in particular the emergence of social hierarchies, has far more ramifications than this. It provides a general theory of ultimate human motivations and their consequences for human decision making and action, based on the centrality of the evolutionary goals of survival, reproduction, and successful parenting. It acknowledges that human social orders have a long, including prehuman, evolutionary history that has had a bearing on subsequent possibilities. And it represents evolution as a process of branching differentiation rather than a directional trend. If there are any directional trends in the evolution of human societies, as indeed there appear to be, they emerge as a by-product

of directionless selection processes in specific local contexts, just as the major transitions in biological evolution did.

Moreover, evolutionary theory offers a set of theoretically well-founded mechanisms with predictive consequences for explaining social change. They include models of the impact of the predictability of resources on the existence of private property (Bowles 2004, chap. 11) and on the changing nature of social competition (Boone 1992), as well as models specifying the conditions for the emergence of ethnic boundaries and the processes involved (McElreath, Boyd, and Richerson 2003). One classic example of such a mechanism is costly signaling (Bliege Bird and Smith 2005; Neiman 1997; Boone 2000), the idea that the quality of display gives a true indication of some underlying quality of the displayer to individuals who will gain in some way by making a correct assessment of that underlying quality; at the same time, as a result of making that correct assessment, they will act in ways that also benefit the signaler. Thus, in societies where patrons compete for clients and clients for patrons, honest signaling of underlying capacities can develop, for example, by patrons of their capacity to provide food for clients by the giving of extravagant feasts. The marginal cost to a would-be patron who really does have access to very large quantities of resources will be less than it is to someone with poorer resources, and the prospective client has a strong interest in getting the choice right. As Boone (2000) shows, such situations won't necessarily stay in equilibrium; for example, if interannual variance in subsistence productivity increases, a variety of complex and in some respects counterintuitive consequences will ensue. Such models offer enormous predictive possibilities for archaeologists trying to understand variations in social status signaling, which are actually also measures of the variation in social status by virtue of their honest signaling properties.

Finally, the individualistic starting point of Darwinian perspectives does not assume the existence of societies as functioning entities but raises the question of how any sort of social order

can come into existence and be maintained or change through time, and it provides tools for addressing this, especially those of evolutionary game theory (see, e.g., Bowles 2004, chap. 2; Skyrms 1996). At its core are social agents, individuals with norms, dispositions, knowledge, and resources, who make decisions in their own interests in the light of constraints and opportunities, who at times innovate and at others follow existing practices. The aggregate outcomes of the actions of social agents are usefully understood from within a game theoretic framework, in that those social and economic strategies that produce beneficial outcomes for the agents will spread through the members of the groups concerned, and they may themselves be replaced if circumstances change. Moreover, when outcomes are aggregated, they can have consequences unintended by any individual social actor, including the emergence of qualitatively new forms of social and economic patterns. Why do these local actions produce broad-scale social evolutionary patterns? There are three reasons. First, successful patterns of action spread because they are perceived to be successful by others in similar situations. Second, selection on social, cultural, and economic strategies will often result in similar outcomes in the face of similar situations. Third, processes of self-organization operate in social interactions, leading to convergence on various kinds of “attractors.” Accordingly, to understand large-scale transformations, we do not need to indulge in broad abstractions but to carry out theoretically informed analyses of particular situations. The chapters in this section illustrate some of the explanatory possibilities of taking an evolutionary approach.

Dunbar is concerned with the factors affecting the emergence of distinctively human forms of sociality during the time since the last common ancestor when the hominin lineage came to differ from other primates. In multilevel social systems such as those found in primates, individuals’ decisions occur within a group and affect everyone else’s fitness. The question then arises, What limits group size? In primates grooming is

the bonding agent, and grooming time is a linear function of group size. Bonding large dispersed groups was a major problem during hominin evolution. If humans bonded their groups as primates do, grooming time would be about 45 percent of total day time. In fact, mean social time is exactly 20 percent of available time, the same limiting value seen in nonhuman primates. Language offers a partial solution to the problem of bonding, but although it is ideal for information transfer, it cannot replace the emotional aspects of grooming and the pleasurable sensations it produces. Dunbar offers a series of arguments for the view that the gap has been filled by the evolution of laughter, singing, religion, and storytelling as bonding mechanisms.

Fortunato and Mace analyze the evidence for Indo-European marriage practices from a human behavioral ecology perspective, focusing in particular on wealth transfers at marriage through the application of the phylogenetic comparative method to cross-cultural data on this subject. They find that an association between bride wealth and polygyny and between dowry and monogamy cannot be accounted for simply as a result of the historical relatedness of the societies concerned but that wealth transfer practices and forms of marriage must have evolved together and therefore must be functionally interrelated. In the general theoretical behavioral ecology model for the relationship between mating systems and patterns of parental investment in male or female offspring, it is changes in the former that drive changes in the latter. However, Fortunato and Mace’s results indicate that the opposite is the case with Indo-European groups, leading them to discuss alternative models, in particular the economic model of the relation between wealth transfer and marriage systems proposed by Goody (1976). This does predict that changing patterns of wealth transfer should drive changes in marriage practice, but it needs to be tested in the same way as the initial model. The chapter concludes with a discussion of some of the methodological issues that arise with using phylogenetic comparative methods in the way the authors advocate.

Wiessner tackles related issues in her chapter by taking Trivers's (1974) theory of parent-offspring conflict as a framework for looking at marriage choices and who makes them. She uses data she has collected from the Ju/'hoansi (!Kung) Bushmen, foragers of Botswana and Namibia, to address a number of questions concerning the goals and preferences of parents and children in relation to marriage, the extent of parent-child conflict and its outcomes, and the broader implications of the outcomes in relation to material culture and social evolution. She concludes that marriage does indeed constitute an important arena for parent-offspring conflict and that underlying conflicts of interest around who controls marriage have significant implications for social evolution and material culture. Parental control will lead to an emphasis on displaying family wealth and reputation. In contrast, when children make their own decisions about who to marry, family-centered displays are not important, and personal qualities such as beauty and prowess are what is signaled. Because the outcome of conflicts depends on power, external changes in the economic system can shift the balance of power between parents and children. Wiessner shows how recent changes have led to a shift in favor of children in the making of marriage decisions, which has had a variety of consequences, including contributing to the decline of the *hxaro* exchange system.

The problem Plourde addresses in her chapter concerns the origins of the value of prestige goods in the absence of rank and wealth differences, and she develops a model to explain the role played by such goods in the processes leading to the emergence of hierarchical institutions. On the basis of arguments put forward by Henrich and Gil-White (2001), she proposes that prestige goods originate as costly signals of personal success and skill that result from an increase in interindividual prestige competition based on variation in skill levels; this competition in turn stems from increasing group size and from situations where the range of skills and knowledge existing within the group is

increasing. The process moves up a gear if cultural group-level selection processes favor those groups that are more successful at collective action. If such action depends on the existence of a leader, this becomes a new area of within-group competition where the costly signaling represented by prestige goods becomes even more important. The model thus grounds the role that prestige goods play in the development of ranking and hierarchy in the operation of individual strategies that already exist in societies where these are absent.

The remaining three chapters in this section are archaeological case studies. Kohler and colleagues use the superb settlement and environmental data they have gathered for the Mesa Verde region of the southwestern United States for the period 600–1300 CE, together with the sophisticated modeling tools they have developed, to test the hypothesis proposed by Turchin and Korotayev (2006) that prestate societies exhibit a deterministic relationship between population size and incidence of internal warfare or sociopolitical instability. Important to their thesis is that both population size and incidence of instability are dynamic variables: population growth eventually causes an increase in instability, with a lag, whereas increased instability, also with a lag, eventually leads to decreases in population size. For much of the sequence, the model's predictions are confirmed, in that relative absence of warfare has a positive impact on population growth; and once population levels are high, violence tends to follow, not only cutting off population growth but actually stimulating population decline—for example, by leading to emigration. However, the model does not fit for the period from the late 900s to the mid-1100s because during this time, the growth of violence leads the growth of population rather than lagging behind it, possibly as a result of external warfare associated with the Chacoan expansion. The authors suggest that this may point to a general limitation of the model as it stands because the situations that it postulates, where exogenous factors are

not important over long periods of time, are not very common.

In their chapter, Kennett and colleagues use a model from evolutionary population ecology known as the ideal free distribution, and the related ideal despotic distribution, as a basis for generating predictions about the relationship among demographic expansion, resource intensification, and the emergence of institutionalized social hierarchies on California's Northern Channel Islands during the Late Holocene (3,000–250 years BP). On the basis of habitat suitability, population density, and differential access to resources, this model predicts the manner in which heterogeneous habitats will fill with population, as a function of density-dependent declines in environmental suitability resulting from increasing exploitation. With increased population and the expansion of people into increasingly marginal habitats, the costs associated with emigration become higher than those of being subjugated by one's own group members, thus the emergence of social hierarchies will tend to be favored. GIS environmental coverages are used to rank habitats according to the availability of drinking water, terrestrial resources, and marine resources. The available archaeological data concerning the date at which particular locations were occupied and dates for the first appearance of social hierarchies are consistent with the demographic, economic, and sociopolitical predictions of the model, suggesting that its implications are worth further investigation and testing.

In the final chapter, Kuijt's case study of changing settlement systems in the Pre-Pottery Neolithic B (PPNB) period of the Levant (ca. 11,000–8,000 years BP) demonstrates the enormous potential for the evolutionary study of social change that now exists with the increasing availability of paleoenvironmental data that make it possible to test models of the impact of climate change on human populations and the way they were organized. It focuses in particular on the aggregation of people into large densely occupied villages in the Late PPNB period and the subse-

quent abandonment of those villages with a return to a more dispersed settlement pattern. While the appearance of Middle PPNB villages is associated with an increase in rainfall that may have improved crop-growing conditions, the large, so-called mega-villages of the Late PPNB cannot be linked to any further climate changes and may be associated with increased control of labor at a time when there is strong evidence for economic intensification. Their abandonment, on the other hand, coincides with a period when there is an initial increase in rainfall (ca. 8,700 years BP) followed by a long-lasting major reduction that was also associated with a significant temperature decrease. The effects of this precipitation reduction and cooling would probably have included a reduction in the predictability and success of harvests, as well as a narrowing of the spatial range of useful resources. It seems that despite the size and complexity of these villages, they lacked the organizational and economic capacities to adjust to the new conditions, so that it became adaptively advantageous to live in smaller-scale communities and to practice more mobile ways of life. There was no continuous directional trend to greater social complexity or increased inequality.

CONCLUSION

The chapters in this volume show the enormous range of ways in which Darwinian evolutionary ideas can lead to productive empirical research, which is the touchstone of any worthwhile theoretical perspective. They also demonstrate the synthetic nature of the approach, the way in which a variety of processes on different temporal and spatial scales can be brought into relation with one another and be shown to have mutual-causal effects. This does not mean that the approach is in danger of becoming a homogeneous one. On the contrary, there are major disputes among evolutionists about what are the key explanatory factors in particular cases—for example, that between Hawkes and colleagues, on the one hand, and Kaplan and colleagues, on

the other, about the processes that have affected the evolution of human life histories and the nature of male and female role differences (e.g., Kaplan et al. 2000; Hawkes et al. 2000); or between those who think that the characteristics of human societies can be explained in terms of inclusive fitness and those who emphasize the need to take specifically cultural processes into account (reviewed in Henrich 2004). It is also not being claimed that the adoption of a Darwinian perspective involves a complete rejection of the goals and achievements of earlier anthropologists and archaeologists. On the contrary, much evolutionary work on cultural transmission, for example, echoes the culture history of the first half of the twentieth century and rightly brings many of the issues it addressed back to center stage. What is being claimed, though, is that the adoption of an explicitly Darwinian approach, and of the secure theoretical foundations on which that approach is based, will enable those goals to be addressed far more successfully than they have been in the past.

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Understanding Cultural Transmission

TWO

Placing Archaeology within a Unified Science of Cultural Evolution

Alex Mesoudi and Michael J. O'Brien

MESOUDI, WHITEN, and Laland (2006) have argued that culture can be studied within a single overarching evolutionary framework, just as different branches of biology are linked within a similar synthetic framework. Here we explore how archaeology fits into this framework, primarily as a means of studying macroevolutionary patterns. This is illustrated by the use of phylogenetic methods to analyze artifact distributions (e.g., Buchanan and Collard 2008; Jordan and Shennan 2003; O'Brien, Darwin, and Lyman 2001; O'Brien and Lyman 2003; O'Brien et al. 2002; Tehrani and Collard 2002). We argue that macroevolutionary archaeological work would benefit from a more detailed and explicit consideration of microevolutionary mechanisms of cultural transmission, as exemplified by Bettinger and Eerkens's (1999) use of Boyd and Richerson's (1985) cultural-transmission biases to account for geographic differences in artifact variation. This is reinforced by our own experimental work and highlights how a plurality of methods—archaeological, computer modeling, and experimental—and scales—macro- and microevolutionary—can provide a fuller account of

past cultural evolution than can any single method or scale. Finally, we point out that archaeology can benefit from comparative studies of social learning in other species and that a “cultural evo-devo” perspective can potentially link ethnographic, psychological, and archaeological theory and data.

ARCHAEOLOGY AS A MACROEVOLUTIONARY SCIENCE

In a recent paper published in *Behavioral and Brain Sciences*, Mesoudi, Whiten, and Laland (2006) argue that we can take advantage of the similarities between cultural and biological evolution (see Mesoudi, Whiten, and Laland 2004) in order to model the structure of a science of cultural evolution after the structure of the science of biological evolution. In essence, if both cultural and biological change are governed by the same underlying Darwinian processes of variation, differential selection, and the inheritance of selected variants, then the cultural and biological sciences should broadly share the same methodological and conceptual divisions. Figure 2.1 shows the resulting structural

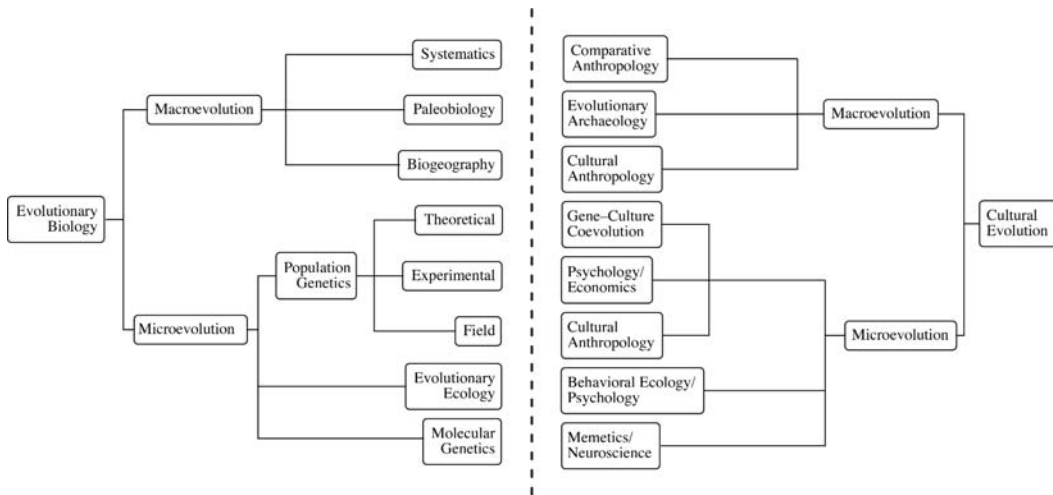


FIGURE 2.1 The structure of a science of cultural evolution (right) mapped onto the parallel branches of evolutionary biology (left) (from Mesoudi et al. 2006).

mapping that links the subdisciplines of evolutionary biology to their existing or potential cultural counterparts.

One of the branches shown in figure 2.1 is evolutionary archaeology (Dunnell 1980; O'Brien and Lyman 2000, 2002), the cultural parallel of paleobiology. In both disciplines, researchers are interested in identifying past biological/cultural forms and reconstructing lineages and clades of those forms, thus revealing evolutionary relationships among the forms. In paleobiology, this has been successfully carried out ever since the Modern Synthesis of the 1930s and 1940s (Huxley 1942), with the principles of genetic inheritance providing the mechanism needed to link evolutionary lineages and clades. In archaeology, it is only recently that lineages of artifacts have been explicitly seen as being causally connected by inheritance, or cultural transmission (see the essays in Lipo et al. 2005). O'Brien and Lyman (2000, 2003) have referred to this as the assumption of *heritable continuity*, distinguishing it from mere *historical continuity*, in which forms are in sequence but are not necessarily causally linked by cultural transmission. The assumption of heritable continuity allows a truly Darwinian evolutionary archaeology (O'Brien and Lyman 2000, 2002; Shennan 2002). Put

more forcefully, evolutionary archaeology *demands* such an assumption.

The parallel goals of paleobiology and evolutionary archaeology allow archaeologists not only to adopt similar underlying theoretical or conceptual assumptions as paleobiologists (such as heritable continuity) but also to borrow and adapt specific methodological tools that have been developed by paleobiologists. Perhaps the most important of these are cladistic, or phylogenetic, analyses. Cladistic methods were originally developed and are extensively used by biologists to reconstruct the evolutionary history of species based on their morphological, behavioral, and/or genetic similarities (Harvey and Pagel 1991; Hennig 1966). Only recently have these methods been applied to cultural data sets (e.g., Collard, Shennan, and Tehrani 2005; Gray and Atkinson 2003; Gray and Jordan 2000; Holden 2002; Jordan and Shennan 2003; Mace and Pagel 1994; O'Brien et al. 2001, 2002; O'Brien and Lyman 2003; Rexová, Frynta, and Zrzavý 2003). The main strength of such methods lies in the formal differentiation of homologous traits, which were inherited from a common ancestor, from analogous traits, which evolved independently in unconnected lineages (figure 2.2). This distinction is necessary in order to reconstruct accurate evolutionary

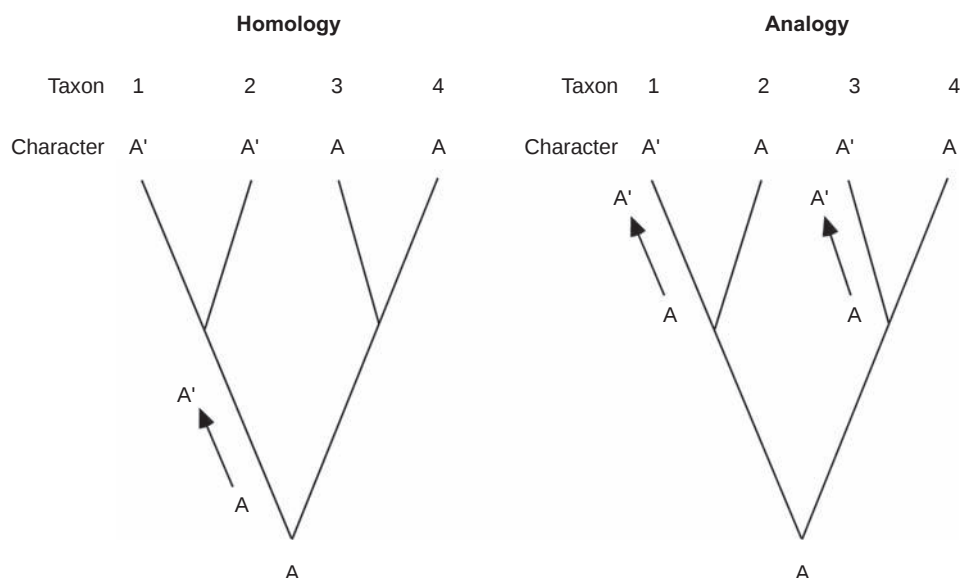


FIGURE 2.2 **The difference between homologous characters (attributes) and analogous characters.** In the diagram on the left, an ancestor produces two lines, each of which splits into two lines, producing taxa 1–4. Note that one set of descendants (taxa 3 and 4) carries the ancestral character state (A), whereas in the other set, the descendants (taxa 1 and 2) share a derived character state (A'). That derived character state is homologous to taxa 1 and 2, meaning that they share it because their common ancestor had it. In the diagram on the right, taxa 1 and 3 each have the derived state, A', but it is analogous to those two taxa, meaning that they evolved it independently as opposed to inheriting it from a common ancestor.

histories of either biological species or cultural artifacts (Lyman 2001).

For example, O'Brien et al. (2001, 2002; O'Brien and Lyman 2003) performed a phylogenetic analysis of Paleoindian period projectile points from the southeastern United States (figure 2.3), providing a more methodologically and conceptually rigorous understanding of the past spread of projectile-point technology in that region than is obtained using alternative methods that do not distinguish between analogous and homologous features, such as phenetics (numerical taxonomy) or informal verbal arguments made on the basis of supposed “stylistic” similarity. Similarly, Tehrani and Collard (2002) used phylogenetic methods to reconstruct the history of Turkmen textiles based on their patterned designs (figure 2.4), finding an earlier period dominated by phylogenesis, involving the branching of separate lineages, followed by a later period of ethnogenesis, involving crossing between lineages. This finding calls into question the common critique (e.g., Moore

1994; Terrell, Hunt, and Gosden 1997) that phylogenetic methods cannot account for the reticulated structure of cultural transmission because of the assumed prominence of horizontal cultural transmission in human history.

On closer inspection, this dichotomy between a branching, divergent biology and a reticulated, convergent culture is largely illusory. Ethnographic evidence suggests that vertical cultural transmission plays a major role in human culture (Guglielmino et al. 1995; Hewlett, De Silvestri, and Guglielmino 2002; VanPool, Palmer, and VanPool 2007), whereas horizontal cross-lineage transfer of genetic material is common in many biological species (Abbott et al. 2003). Accordingly, Collard, Shennan, and Tehrani (2005) found that twenty-one cultural data sets fit just as well as twenty-one biological data sets to a phylogenetic tree model.

Although trees produced through methods such as parsimony, maximum likelihood (Hall 2001), and Monte Carlo Markov chain Bayesian techniques (Huelsenbeck, Rannala, and Masly

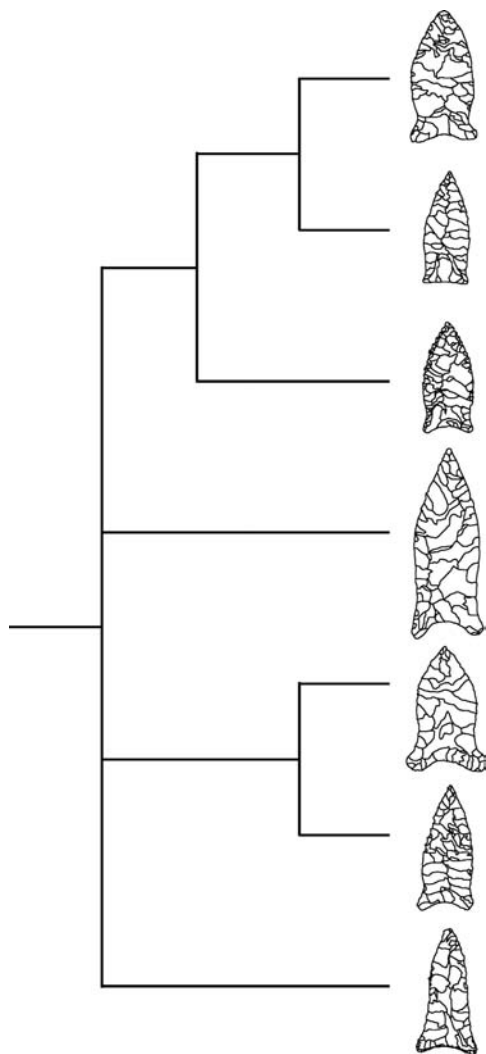


FIGURE 2.3 A portion of a much larger phylogenetic tree of projectile point classes from the southeastern United States, illustrating divergence from a single common ancestor (after O'Brien and Lyman 2003).

2000) appear to have considerable promise for phylogenetic ordering, it is important to note that they are but one weapon in the social scientist's arsenal. Other methods—split-decomposition graphs (Bandelt and Dress 1992), tests for serial independence (Abouheif 1999), iterated parsimony (McElreath 1997), network analysis (Lipo 2005), tests for matrix correspondence (Smouse and Long 1992), assessment of hierarchical cluster structure (Pocklington 2005), and seriation (Lyman and O'Brien 2005)—

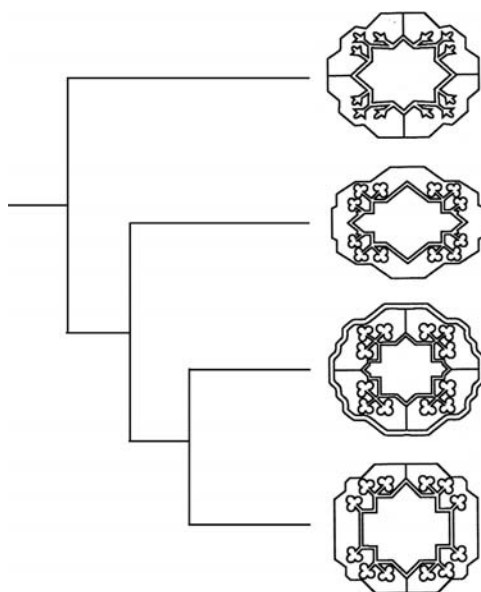


FIGURE 2.4 A phylogenetic tree of Turkmen textile designs prior to the Russian invasion of Central Asia (after Tehrani and Collard 2002).

should be used in tandem with tree-producing methods in order to address questions of phylogeny.

Another group of archaeologists has adopted a different tool from evolutionary biology to help explain patterns in the archaeological record. Following Cavalli-Sforza and Feldman (1981), Neiman (1995), Shennan and Wilkinson (2001), and Bentley and Shennan (2003) have applied to archaeological data the neutral-drift model originally developed by population geneticists (Crow and Kimura 1970). Hence, Neiman (1995) demonstrated that random copying can account for changes in decorative patterns found on Illinois pottery, and Shennan and Wilkinson (2001) found evidence for a nonrandom, anti-conformist copying bias in Neolithic central European pottery. The latter example highlights how the neutral-drift model can be usefully used as a null hypothesis, so that when artifact frequencies deviate from frequencies expected by random copying, this indicates the operation of other cultural transmission biases, such as conformist, nonconformist, or prestige-based biases.

LINKING CULTURAL MICRO- AND MACROEVOLUTION

Phylogenetic methods such as those just discussed are used to study biological or cultural *macroevolution* (figure 2.1). That is, they are used to identify patterns and trends in long-term change over multiple generations using large samples of specimens. The major advance within evolutionary biology brought about by the Modern Synthesis was that the macroevolutionary patterns observed by paleobiologists (e.g., Simpson 1944) came to be seen as the long-term population-level result of the microevolutionary principles of genetic inheritance discovered by geneticists.

Viewing cultural macroevolution and microevolution within a single overarching framework (Mesoudi, Whiten, and Laland 2006), and recognizing that lineages and clades of artifacts are causally linked by cultural transmission (Lyman and O'Brien 2000), leads us to a similar synthesis for evolutionary archaeology. That is, large-scale patterns observed in the archaeological record can be (partly) seen as the result of specific biases in cultural transmission at the microevolutionary level (Bettinger and Eerkens 1999; Boyd and Richerson 1992; Lyman and O'Brien 2001). For archaeologists, just as for paleobiologists, these past microevolutionary inheritance or transmission processes cannot be directly observed at the individual level. Rather they must be inferred from (often incomplete) historical population-level data. This is not to say that differences in the processes of cultural transmission are the only source of archaeological patterns; environmental factors such as rainfall and climate or features of geography will be important in many cases. Nevertheless, the details of cultural transmission at the individual level likely will play some role in generating measurable patterns in artifact form and variation at the population level.

What does it mean to consider the microevolutionary details of cultural transmission when analyzing macroevolutionary patterns and trends? In a sense, the debate highlighted here

over whether culture is branching or convergent is a debate over transmission, with the former assuming vertical cultural transmission and the latter assuming horizontal cultural transmission. As Borgerhoff Mulder, McElreath, and Schroeder (2006) point out, however, there is also an unstated assumption that this transmission is occurring at the level of groups rather than the level of individuals that was originally intended by Cavalli-Sforza and Feldman (1981) when they first used the terms *horizontal* and *vertical* in this context. Vertical transmission at the individual level can produce blending if individuals marry into new groups, whereas horizontal transmission can produce branching if it is restricted within groups. Many of the studies used to justify an assumption of vertical transmission, such as Guglielmino et al. (1995), are ethnographic studies of transmission within groups and may not bear on whether culture as a whole is branching or blending (Borgerhoff Mulder, Nunn, and Towner 2006).

One study that attempted to explicitly link different cultural transmission processes to macroevolutionary patterns is Bettinger and Eerkens's (1999) comparison of projectile-point variation in the western United States. Bettinger and Eerkens observed that different attributes (e.g., width and weight) of projectile points found in eastern California were largely uncorrelated (table 2.1), which they argued was because the designs of points in this region originally spread by *guided variation* (Boyd and Richerson 1985), in which individuals acquire a cultural trait, then modify it through individual trial and error. Hence, each attribute is subject to separate individual trial and error, causing the attributes to vary independently. Conversely, projectile points found in central Nevada, which feature uniform designs with often highly correlated attributes (table 2.1), were argued to have spread by *indirect bias* (Boyd and Richerson 1985), with individuals copying wholesale the design of the single most-successful or prestigious model. If everyone is copying the design of a single model, then point designs in the

TABLE 2.1. *Correlations (Pearson's r) between Different Projectile-Point Attributes from Nevada and California*

		AXIAL	MAXIMUM	BASAL	NECK		DISTAL	PROXIMAL	
		LENGTH	WIDTH	WIDTH	WIDTH	THICKNESS	SHOULDER	SHOULDER	WEIGHT
							ANGLE	ANGLE	
Maximum length	NV	1.00	0.58 ^a	0.48 ^a	0.51	0.51 ^a	−0.19	−0.34	0.86
	CA	1.00	0.24	0.07	0.21	0.15	−0.24	−0.24	0.76
Axial length	NV		0.59	0.49 ^a	0.51 ^a	0.49 ^a	−0.18	−0.33	0.86
	CA		0.22	0.04	0.16	0.14	−0.24	−0.27	0.74
Maximum width			NV	0.44	0.72	0.12	−0.48	−0.53 ^a	0.62
			CA	0.54	0.69	0.26	−0.47	−0.08	0.71
Basal width				NV	0.71	0.21	0.11	0.26	0.80 ^a
				CA	0.78	0.05	−0.06	0.31	0.14
Neck width					NV	0.23	−0.15	−0.15	0.61
					CA	0.11	−0.06	0.15	0.40
Thickness						NV	0.14	−0.02	0.70
						CA	0.03	−0.02	0.57
Distal shoulder angle							NV	0.53 ^a	−0.12
							CA	0.16	−0.38
Proximal shoulder angle								NV	−0.21
								CA	−0.01

^aIndicates a significantly stronger correlation in the Nevada sample than in the California sample, as predicted by the model (Boyd and Richerson 1985).

SOURCE: Bettinger and Eerkens (1999).

population as a whole will become uniform, and their attributes will correlate. Here Bettinger and Eerkens demonstrated a potential link between individual-level cultural transmission (guided variation vs. indirect bias) and population-level archaeological data (uncorrelated vs. correlated point attributes). We encourage more such studies that test hypothesized links between cultural micro- and macroevolution.

EXPERIMENTAL SIMULATIONS
OF CULTURAL TRANSMISSION

Experimental simulations of cultural transmission offer another means of testing hypotheses regarding the effect of transmission biases on macroscale evolutionary change (Mesoudi 2008). Evolutionary biologists are increasingly studying biological evolution experimentally in the laboratory using microorganisms (Cooper,

Rozen, and Lenski 2003), often addressing issues regarding biological macroevolution that previously only the fossil record could address, such as punctuated equilibria, long-term adaptation in rugged fitness landscapes, and the evolution of sexual reproduction. The cultural equivalent of such experimental simulations would involve transmitting cultural information—in the form of attitudes, knowledge, behavioral practices, and group norms—along multiple “generations” of participants in the psychology laboratory, and measuring the effect on the transmission of that information of different modes of social learning, different types of information, different social networks, and so on.

Although such studies have been few and far between in the history of psychology, a number of studies in recent years have begun to address such questions. Some have used Bartlett’s (1932) linear transmission chain method either

to identify cognitive or memory biases that affect the transmission of written texts (Bangerter 2000; Kashima 2000; Mesoudi and Whiten 2004; Mesoudi, Whiten, and Dunbar 2006) or to study the transmission of behavioral strategies among players of economic games (Schotter and Sopher 2003). Others have experimentally tested the predictions of formal mathematical models regarding when people should engage in different strategies of social learning and when they should rely on individual learning (Kameda and Nakanishi 2002, 2003; McElreath et al. 2005). Such methods have the potential to provide important insights into both specific archaeological processes and more general principles regarding cultural transmission that can inform archaeological work.

Experimental methods have several advantages over historical methods, such as the ability to rerun history in multiple replications; to access complete, uninterrupted data; to directly compare fitness or efficacy at different points in time; and to manipulate and control environmental conditions and experimental variables. Although there are several limitations on the use of experimental simulations to study biological evolution, such as the long generation time of some species or the fact that the majority of species in the fossil record are now extinct and cannot be studied, these limitations may not be so severe for cultural evolution. Cultural practices or skills can be acquired within a single generation, and many prehistoric artifacts are still in use by traditional societies or amateur enthusiasts (VanPool, Palmer, and VanPool 2008).

Experimental simulations alone can never definitively answer questions regarding past cultural change. Rather, they can complement existing archaeological methods and computer models to provide a more complete understanding of the past. Accordingly, in past work (Mesoudi and O'Brien, 2008) we conducted an experimental simulation of the patterns observed by Bettinger and Eerkens (1999), in which groups of participants design their own "virtual projectile points" and engage in social and individual learning. These experimental

simulations confirm that the transmission biases (guided variation and indirect bias) hypothesized by Bettinger and Eerkens to have generated their archaeological patterns (low and high inter-attribute correlations, respectively) generate similar patterns of variation in our experimental data, thus increasing our confidence in this cultural transmission explanation of Great Basin artifact variation.

CULTURAL TRANSMISSION IN OTHER SPECIES

So far, we have briefly discussed a number of different modes of cultural transmission, such as Cavalli-Sforza and Feldman's (1981) vertical and horizontal transmission or Boyd and Richerson's (1985) guided variation and indirect bias. However, it may be instructive to go beyond these differences by drawing from the wider literature regarding animal social learning, within which there has been extensive debate over the precise underlying social learning mechanisms exhibited by various species in different contexts (e.g., Avital and Jablonka 2000; Fragaszy and Perry 2003; Hurley and Chater 2005; Whiten et al. 2004). Indeed, the transmission biases discussed in the prior sections are a small subset of all possible cultural processes.

Regardless of whether nonhuman species have "culture" (Boesch and Tomasello 1998; Laland and Hoppitt 2003; Whiten 2005; Whiten, Horner, and Marshall-Pescini 2003), humans are likely to share many social-learning mechanisms with other species as a result of either descent from a common ancestor or convergent biological evolution. Note that we treat the terms *social learning* and *cultural transmission* as broadly synonymous, with no connotations as to which mechanisms can or cannot support culture, however culture is defined.

Much of the literature has been concerned with specifying exactly what one individual is learning from another individual and how this learning is achieved. Whiten et al. (2004) identify a number of distinct processes that address these issues, including *imitation*, where an

individual copies the motor action of a model; *emulation*, where an individual copies the result or the goal of a model's action; *affordance learning*, where an individual learns from a model about the physical properties of an object; *observational conditioning*, where an individual learns from the model the positive or negative value of an object; and *stimulus enhancement*, where an individual's attention is directed by a model toward an aspect of their shared environment. To these behavioral processes, which were delineated primarily by primatologists, we can add for humans spoken and written language (Christiansen and Kirby 2003), which undoubtedly significantly transformed cultural transmission and cultural evolution in our species.

With respect to archaeology, any or all of these behavioral and linguistic processes may have been operating when people constructed tools, and different processes may have led to different patterns in the archaeological record. For example, Tomasello, Kruger, and Ratner (1993) have argued that of the behavioral processes just listed, only imitation has the necessary high fidelity to sustain the accumulation of cultural modifications over time that appears to typify many archaeological seriesations. Anthropologists, on the other hand, have historically stressed the importance of symbolic communication, such as language, in the transmission of culture (e.g., White 1962). Perhaps experimental and computer simulations of such processes might indicate which is necessary for the long-term cultural transmission and evolution of different artifacts.

In addition to these broad processes affecting how information is learned from others, other factors affecting what is learned include when individuals learn from each other and from whom they learn (see, e.g., Laland 2004). Examples of “when” strategies derived from theoretical analyses and experimental studies are the self-explanatory “copy when established behavior is unproductive,” “copy when individual learning is costly,” or “copy when aspects of the environment are uncertain.” The cultural-trans-

mission biases discussed earlier are examples of Laland's “who” strategies: “copy kin” (vertical transmission), “copy unrelated individuals” (horizontal transmission), “copy the majority” (conformist bias), and “copy successful/prestigious individual” (indirect bias). Finally, cultural transmission can be guided by content biases (Henrich and McElreath 2003), where the intrinsic quality of information affects its likelihood of transmission, or where biologically evolved or culturally shaped features of human cognition bias the acquisition of certain types of information over others. To reiterate, human cultural transmission was likely to have been (and likely still is) a complex interplay among these different processes and biases, and only by using quantitative methods such as gene culture coevolution models or phylogenetic analyses, together with controlled experimental simulations, can we begin to unravel this complexity.

CULTURAL EVO-DEVO

Missing from figure 2.1, but mentioned by some of the commentators in Mesoudi, Whiten, and Laland (2006), is the emerging field of evolutionary developmental biology, or “evo-devo” (Carroll 2005; Müller and Newman 2003). This approach is gaining increasing influence within biology, and there have been several calls for it to be integrated into the evolutionary synthesis (Kutschera and Niklas 2004). In biology, evo-devo concerns how genetically and environmentally influenced developmental processes interact with longer-term evolutionary change. A “cultural evo-devo” in an archaeological context would concern the behavioral processes by which material artifacts are generated by culturally transmitted information stored in the brain and how this process interacts with macroevolutionary change.

It might be useful in this context to treat cultural traits, including and especially artifacts, as “recipes” (Lyman and O'Brien 2003; Neff 1992). These comprise the materials required to construct an artifact (the “ingredients”) and the behavioral rules required to construct and use

the artifact (the “instructions”). Similarly, cognitive psychologists (e.g., Weber, Dixon, and Llorente 1993) have proposed that people represent artifacts as interlinked, hierarchical knowledge structures, incorporating behavioral scripts governing their construction and use, much like the recipe concept. It is also notable that biologists often use the recipe metaphor to describe the development of organisms from genetic information (Dalton 2000; Ridley 2003). There is real potential here to move beyond the metaphors and incorporate behavioral data from ethnographic studies of artifact construction and use, psychological data regarding the representation of artifact knowledge in the brain, and archaeological data regarding the evolution of artifacts. This is made easier within a single overarching evolutionary framework.

CONCLUSIONS

We have argued that placing archaeology within a larger evolutionary framework, such as the one suggested by Mesoudi, Whiten, and Laland (2006), can provide a more comprehensive and accurate account of the archaeological record than can more traditional nonevolutionary theoretical positions. Darwinian evolution naturally places emphasis on cultural transmission, making explicit the assumption of heritable continuity that links lineages of artifacts. The fact that archaeologists face the same questions as paleobiologists encourages the use of methods developed by biologists, such as phylogenetic analyses or drift models, to be applied to archaeological data. The synthetic nature of the evolutionary framework also encourages a more detailed consideration of the microevolutionary processes of cultural transmission and how they generate macroevolutionary patterns. This can be done using experimental simulations and computer models of underlying transmission processes. Comparative studies of human and nonhuman social learning can usefully inform archaeology, and adopting a cultural evo-devo perspective can potentially link ethnographic, psychological, and archaeological data. These interdisciplinary links

naturally follow from placing archaeology within a larger unified cultural evolutionary synthesis.

In closing, we remind readers that there are limitations on what we can and cannot know about cultural transmission, especially when relying on incomplete and ambiguous archaeological data. At the same time, however, we should not be dissuaded from continuing to pursue evolutionary studies in archaeology. While empirical studies of past cultural transmission and evolution are undoubtedly difficult, and the phenomena under investigation are undoubtedly hugely complex, evolutionary biologists face similar difficulties in the face of similarly daunting complexity. For example, geneticists face the same difficulties in defining a unit of biological inheritance as anthropologists do in defining a unit of cultural transmission. Indeed, far from having a single, universally agreed-on definition, the “gene” actually has multiple, often mutually incompatible meanings used at different times by different biologists in different contexts (Stotz and Griffiths 2004).

Paleobiologists work with the same kinds of fragmentary data as archaeologists do, yet evolutionary biology has thrived through the use of simple assumptions and models and an overarching theoretical framework that unites disparate disciplines and methods. Discoveries in genetics and paleobiology have been made that were unthinkable mere decades ago. Perhaps a few decades from now, future evolutionary archaeologists will look back on similarly dramatic progress in their own field.

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THREE

Human Communication as Niche Construction

Robert Aunger

CULTURAL TRANSMISSION is essentially the idea that beliefs and values are passed from generation to generation. The question I would like to address in this chapter is, How does this happen? In particular, what is the mechanism? In the absence of a deep understanding of the process by which people come to have similar ideas, a variety of metaphors have been used. My purpose here is to outline the options for understanding cultural transmission as a process and to analyze their consistency with what we know about cultural change and communication more generally. I conclude with a view that I hope is an advance over the existing alternatives. My proposal makes clearer the role of artifacts in mediating many kinds of communication and takes into account the recent evolution of evolutionary technology—networks of machines that exhibit the qualities of information inheritance, selection, and mutation—as an important phenomenon that interacts with cultural change.

Communication is the process of exchanging information via a common system of symbols, signs, or behavior. A more technical definition, based on information theory, is a process in

which information is transmitted from a sender to a receiver by means of a message that moves through a channel (Shannon and Weaver 1963). Communication is supposed to result in “shared information”—that is, information of similar content in two minds. The common inference is that one individual or agent has acquired this information through a process of information transfer: information moves from one place to another, where it gets stored in some form. As many have noted, this transfer establishes an information inheritance relation between these agents. Others have suggested that chains of communication events might exhibit all the requirements of Darwinian evolution, summarized by the phrase “descent with modification”: mutation, selection and inheritance (Cavalli-Sforza and Feldman 1981; Boyd and Richerson 1985; Durham 1991). Cultural change could then be described as the population-level consequence of many communication chains over a period of time, leading to changes in the relative frequency of cultural variants (Croft 2002).

Even if this is true, the Darwinian approach is wonderfully agnostic about the means by which transfers of information from agent to agent are

achieved. This makes the theory very powerful—it can be applied to many processes, including genes and culture—but it also leaves scientists with work to do in finding out how the information transfer occurs in any given instance. In the absence of clear knowledge, researchers in the social and psychological sciences have been creative in their use of metaphor to describe the process.

THE “NO DYNAMIC” METAPHOR

Some culture theorists don't accept the basic premise that transmission is an important process in cultural change. This can be taken as a kind of default position. Such a position typically argues that “culture” is just the consequence of individual learning. For example, this “no dynamic” alternative is characteristic of some behavioral ecologists who, while they may acknowledge that some social learning occurs in humans, play down its importance in explaining group-level differences in behavior. There is no specific evolutionary dynamic to the ideas that human groups exhibit beside individual-level learning from the environment. At least some suggest that so-called culture is just another phenotypic trait—a quality of an individual, not a group (e.g., Flinn and Alexander 1982). If transmission does happen, it is argued not to have significant independent effects due to the social diffusion of knowledge: individuals still maximize their inclusive fitness in ways expected by standard evolutionary theory; no new phenomena or dynamics are involved in culture. These theorists take advantage of a kind of “phenotypic gambit” (Grafen 1982), arguing that transmission happens in such a way that culture—and any effects it might have on the distribution of knowledge, and hence behavior, within a population—can be ignored. Human behavior can be explained as the interaction of individuals with their environments, and there is little need to invoke other causes underlying behavior such as cultural beliefs and values. Humans learn to respond adaptively to environmental cues without paying

much attention to their conspecifics. For example, one prominent behavior ecologist admits that “I, personally, find ‘culture’ unnecessary” (Betzig 1999, 17).

However, over the past couple of hundred years, some human groups have achieved amazing power over their environments through technological advances, while others continue to eke out a meager subsistence with no economic surpluses. It would be extremely difficult to explain this difference without making reference to differences in group-specific traits and activities, such as engineering principles for constructing superstructures and large-scale infrastructures such as electricity webs and computer networks. The existence of these must be due to socially learned traits. This fact tends to be ignored by human behavior ecologists, who have in large part preferred to study subsistence-level societies (Smith, Borgerhoff Mulder, and Hill 2000).

THE “JUKEBOX” METAPHOR

Evolutionary psychology, with its notion of “evoked” culture, partakes of a variant of this individual learning model. It argues that learning, whether individual or social, is less important in determining so-called cultural behaviors than information stored in evolved mental structures. The transmission of information is occurring not from other people during an individual's lifetime but at the point of birth, in the form of genes. “Culture” (which is not culture at all, because it is not socially transmitted information, the whole point of the culture concept) is put into people's heads by a long-term process of natural selection for ideas that worked in the past to produce adaptive behavior, given the ecological conditions of the species during its evolutionary history (Cosmides and Tooby 1992). “We call similarities triggered by local circumstances *evoked culture*. . . . Observations of similarities and differences do not establish that the substance of human life is created by social learning. In any specific case, we need to map our evolved psychological architecture to know which elements

(if any) are provided by transmission” (Cosmides and Tooby 1992, 210). In this case, a mechanism is implied (although not always explicitly mentioned): culture piggybacks on genetic inheritance, with cultural information being inscribed (somehow) in genes. Presumably cultural information could be incorporated into the genome via a Baldwinian process (Baldwin 1896) or through genetic assimilation (Waddington 1953), so that what has been individually learned becomes at least partly genetic in causation as mutations that support propensities to engage in environmentally appropriate behavior evolve and gradually take over responsibility for producing the behavior.

However, it is unlikely that such a slow process can provide brains with the ability to choose the correct alternative in any cultural context, since culturally appropriate behavior can be sensitive to many novel stimuli (Richerson and Boyd 2005). Of course, the evolutionary psychologists respond that, for new aspects of human environments, no adaptive solution can be expected to have evolved, accounting for the maladaptive nature of many culturally sensitive behaviors in modern societies (e.g., the demographic transition).

The more significant difficulty for this genetic or “individual learning only” position is to explain how groups maintain distinct bodies of knowledge and practice that are not correlated with the ecological experience of the individuals in those groups. Many examples exist of distinct boundaries in cultural behavior between groups living side by side in similar ecological niches (Richerson and Boyd 2005). These differences can only be explained by a group-level process of knowledge retention, presumably through social learning among group members. Transmission, and its effects on the distribution of knowledge, cannot be ignored when human culture is to be explained.

THE “MAGIC” METAPHOR

Used in the enculturation literature (primarily found in social psychology and anthropology),

this metaphor argues that each generation, as it matures and develops, begins to exhibit the cultural traits of the previous generation. The young acquire these traits by an undisclosed means—and thus by “magic.” For example, enculturation is an individual’s “internalization of all aspects of their culture” (DeFleur and Ball-Rokeach 1989, 209).

A somewhat more specific account suggests that one generation “enculturates” the next generation, *en masse*, by passing on their traits, although, again, the mechanism for achieving this transformation of the younger generation is typically unspecified. Thus, enculturation is “a partly conscious and partly unconscious learning experience whereby the older generation invites, induces, and compels the younger generation to adopt traditional ways of thinking and behaving” (Harris 1987, 7). According to etymologists, enculturation is “the process by which human infants learn their culture”; it happens “when culture is passed along from one generation to the next” (Harris 1987, 7).

Not all socialization theorists would argue that no mechanism of transmission exists, only that we currently lack knowledge of how transmission occurs. However, such metaphors also tend to rely on a perceived quality of information that itself is magical and appears not to require a mechanism at all. This is the belief that “culture stuff” can be in one person’s head but passed to another while retaining it as well: information is the one resource that you can give away and still keep yourself (e.g., Pinker 1997). The problem with the idea of costless gift giving or the spontaneous generation of cultural information in naive individuals is that it does not specify the physical substrate of cultural objects; at the same time, it requires the causeless duplication of information. The metaphor thus suggests “action at a distance”—the metaphysical notion that activity in one time and place affects a situation at some point removed, without a physical causal connection. The metaphor also seems to involve the duplication of a physical entity—a quantity of information—at no cost and thus violates

the laws of conservation of mass and energy.¹ A science of communication cannot be built on these metaphysical foundations, so an alternative to the metaphor of communication-as-magic must be found.

THE “SNEEZE” METAPHOR

An interesting feature of culture is the often rapid replacement of one practice with another. A new way of doing something, or a new game or fashion, can spread through a population seemingly overnight. These practices or beliefs often seem to be mindless variations on previous trivial or frivolous behavior. These features suggest that at least some cultural change is rather different from the slow, progressive change of genes. The spread of fashions and fads is often likened to the diffusion of a pathogen-based epidemic, making use of a “culture-as-virus” metaphor. This epidemiological approach places emphasis on the rapid spread of a particular idea or practice through a population, typically without considering the possibility of mutation or variation. The idea is that when a person speaks, ideas pass through the air and can enter other people’s bodies. The communication of information is thus like sneezing: an agent that can produce “symptoms” (i.e., influence behavior) makes the passage from one person to another by moving through the air. Ideas, then, are like viruses. The field of memetics has largely grown up around this metaphor (Dawkins 1976; Blackmore 1999; Aunger 2001, 2002). For example, Dennett (1990, 131) suggests that “memes now spread around the world at the speed of light, and replicate at rates that make even fruit flies and yeast cells look glacial in comparison. They leap promiscuously from [evolutionary] vehicle to vehicle, and from medium to medium, and are proving to be virtually unquarantinable.”

The diffusion of innovation literature (Rogers 1995) also applies this metaphor to the transmission of cultural practices and new technology through a population, producing “epidemics” of new varieties of corn seed (Ryan and

Gross 1943) or the use of novel antibiotics among rural American doctors (Coleman, Katz, and Menzel 1966).

Pathogens, the foundation of biological epidemics, grow and multiply either within the host or a vector species, and then disperse to the next host or vector. However, it is rarely assumed that ideas duplicate themselves within one mind prior to being ejected into the external environment (e.g., in the form of speech); this aspect of the analogy does not transfer from the disease domain to the new domain of culture (the magical duplication of information is supposed to occur again). However, it is crucial to make this assumption for the analogy to be relevant and physically plausible; otherwise, transmission must involve the loss of information during communication: people would have to sneeze away the only copy of the idea they have. If this were true, cultural transmission would become a zero-sum game, with a fixed set of cultural elements being exchanged back and forth through social “learning.” The consequence would be that the accumulation of culture so obvious in recent human history would become difficult to explain.

Alternatively, one can think of the expression of ideas as the phenotype of a mental genotype. Speech in this case is the product of an idea that never leaves the individual’s mind (the “genotype” of an idea presumably being instantiated as a unit of neural memory). However, in this case, the communication-as-infection process becomes Lamarckian because it is the phenotype (speech) that is copied by the “infected” individual. The duplicate of the idea in the receiver’s mind is a phenocopy, being derived from the phenotype rather than directly from the genotype. In this sense, communication becomes an instance of the inheritance of acquired variation (Aunger 2002). If the rate of mutation in ideas is low, and inheritance exact, such transmission could lead to a loss of variation on which cultural selection could work (the Fleeming Jenkins effect). Since we generally see a proliferation rather than reduction in cultural variation around us

(at least as a long-term trend at the global scale), this type of model seems unlikely.

THE “TELEPHONE” METAPHOR

Derived from mathematical communication theory (Shannon and Weaver 1963), the idea here is that “bits” of information are sent through a physical channel from sender to receiver. (Shannon’s approach also has a probabilistic interpretation in terms of the reduction of uncertainty deriving from receiving a bit of information, but I am concerned here with the communication model that derives from the theory.) This metaphor at least makes explicit the need for a channel and for “things” that move through it from one place to another. In this respect, the model is fine—as far as it goes. It also allows for the possibility of randomized mutation in the message, as a result of the action of environmental noise. But it is not fully evolutionary in nature (being designed to explain information flow through telephone networks), because there is no role for selection of messages; that is, the sender and receiver are not conceived as strategic (i.e., biological) agents but as physical mechanisms. This makes the model difficult to apply to biological agents. (Thus, the notion of communication as coded-decoded transfer of information from one party to another also is too broad. Instead, communication should be seen as intrinsically strategic.) In effect, the model doesn’t explain how messages are constructed, selected, or adopted by human beings, or how the relationship between sender and receiver might influence the choice of message nor the likelihood of its adoption. The “telephone” metaphor is, in the end, too physical, too oriented on the transmission component itself. We still lack information about what happens both before and after a message is transmitted “down the line.”

All of these metaphors remain abstract in one sense or another. They are insufficiently realistic in their description of how human communication happens. Communication must be, first, a process with physical causes and consequences

and, second, a process of strategic engagement between agents with potentially conflicting interests. These facts restrict the kinds of models one can legitimately make of the communication process and eliminate those considered so far.

THE “CONSTRUCTION” METAPHOR

In earlier work (Aunger 2002), I developed a model of cultural transmission that avoids these problems. In this model, communication is not seen as the exchange of symbolic objects or abstract “information.” Rather, it is an attempt to manipulate others in the social group using signals or signs (as originally suggested by Dawkins and Krebs 1978).² The goal of communication in this case is get others to engage in behaviors that assist the communicator’s efforts to maximize inclusive fitness.

In this view, communication—the process underlying cultural change—is not fundamentally about the transmission of anything in particular. (By comparison, gene evolution is not really about transmission, either, but rather the “hand-to-hand” construction of offspring DNA strings.) Instead, communication can be defined as *an instance of niche construction using signs, signals, or artifacts that is targeted at changing the behavior of conspecifics*.

The specification of targeting in this definition distinguishes communication from incidental signal production—such as footprints in the sand—which conveys information to others without the intention (or evolved function) of making them behave differently. Accidental transfers of information may occur, but they are assumed not to regularly result in behavior that improves the signaler’s biological fortunes. Communication is thus a narrower concept than social learning, which can involve the inadvertent construction of an environment or situation from which other organisms can better extract information, such as social facilitation (Boysen and Himes 1999).

Social learning thus often occurs without intentionality. In fact, the preponderance of information transmission probably cannot be called

communication because it is unintentional. Animals often observe the behavior of conspecifics to pick up cues about what is important about a place or context, as well as to see how certain kinds of potentially complex skills are best performed. It can be assumed that there is no intention to manipulate conspecifics in this case of “naturalistic” observation, so presumably the model (or accidental demonstrator) is engaging in the most appropriate and relevant practice. It is also easier to evolve culture through this kind of inadvertent social learning than through dedicated dyadic interaction (Panchanathan and Boyd 2004). Even in humans, most skills are learned without formal teaching but rather through observation of cultural practices (Rogoff 2003). The inadvertent transmission of information may therefore be the dominant mode of culture learning. However, I argue that it is also the case that there is an adaptation for intentional transmission—the phenomenon I am calling “communication” in this chapter.

Any activity that has the desired effect on others’ behavior will do as an instance of communication. In humans and other big-brained species (particularly primates), the process of signaling others can be accomplished through various means that make the process more or less indirect. The most direct (and hence simplest) form of communication involves the production of signals such as vocalizations or movements of the body (signs) that can be directly perceived by others. A more complex form of communicative manipulation of the environment involves the production of artifacts that can modify environmental energy forms (e.g., photon streams), producing signals. In this case, an agent rearranges or manipulates the environment in ways that cause others who interact with that aspect of the environment to receive messages. This is social manipulation without communication or “social learning” in the strict sense. An example is the production of a book, which includes pieces of paper imprinted with ink, creating physical surfaces that reflect modified patterns of photons that can be perceived and interpreted through reading. In

this case, artifacts serve as stores of symbolically coded messages that serve as templates of (or, even more actively, transmit) signals to others on your behalf. An even more complex form of communication utilizes artifacts as the communication channel as well—for example, when a page of a book is displayed over the Internet on a computer screen or when reading an e-book.

Communication in this view is a type of environmental manipulation. It involves primary, secondary, and tertiary goals, all of which result in niche construction (*sensu* Odling-Smee, Laland, and Feldman 2004), albeit in different forms. The first objective is to modify the environment by constructing either a signal (i.e., a short-lived perturbation of a medium such as air or water, created through, e.g., speech or gesturing) or a signal template (i.e., the production or modification of an artifact that stores signal-related information, e.g., writing a letter or typing into a computer, which produces changes in the state of RAM to store an e-mail). Both signals and artifacts are aspects of the individual’s niche, so communication begins as an instance of niche construction by the communicator. The secondary goal is to get conspecifics to “consume” the signals produced directly by the sender (e.g., through speech) or by the artifact in which information has been stored (e.g., by watching a computer screen displaying received e-mail). This view suggests that other minds are the equivalent of artifacts: something to be constructed (albeit indirectly) by an organism’s activity. In this instance, the secondary constructive target of communication is *mental* (re)construction by the message receiver. (Of course, the receiver will evolve psychological filters to minimize the infiltration of potentially damaging information, such as attention, categorization, and assessment processes.) The tertiary goal of communicative activity is to eventually influence the behavior of conspecifics, presumably as a result of this (potentially indirect) information transfer to the receiver’s mind. This tertiary goal of communication is to get *conspecifics* to engage in ecological niche constructive activity that is

either beyond the ability of, or could only be done at greater cost by, the communicator—for example, convincing a more senior colleague to approach the head of the firm where one works with a criticism of business operations. It could also be the case that the tertiary goal is to encourage the message receiver to collaborate with the communicator (or third parties) on some cooperative endeavor that achieves an evolutionarily advantageous end state. In any case, the end result is behavior by a conspecific that modifies the communicator's niche in a way that tends to increase the communicator's inclusive fitness.

The traditional view of communication as the face-to-face exchange of spoken words makes it difficult to deal with the complications introduced by artifacts. It might be argued that the role of artifacts is irrelevant, that communication of the same message is still achieved (as when Blackmore [1999] suggests that reading is just imitation). However, such a position would ignore the very large literature on the effects of mediation on the interpretation of messages (Thompson 1996). Marshall McLuhan went too far when he said that the "medium is the message," but certainly a whole discipline—known as media studies—has arisen to study the phenomenon of how technological mediation influences the consequences of communication. Furthermore, artifacts are becoming increasingly like agents themselves, playing significant roles in determining who knows what. This means that their influence must be taken into account when attempting to explain or predict cultural change (Aunger 2002). It therefore seems foolish to ignore—or minimize—the complexities of how information moves through modern technological societies.

It is worth noting that if the goal of communication is to influence one's environment (particularly the behavior of others), then communication may not lead to the replication of information (as some communication theorists would have it—e.g., the Shannon and Weaver tradition). In particular, communication is not designed to create mind viruses, as memetics would suggest (Dawkins 1976). If the goal of communication is

not to copy information, then it is unlikely that selection would have caused the evolution of high-fidelity inheritance mechanisms (i.e., meme replication devices) to support information replication.³

As Sperber and Wilson (1995) emphasize, a listener's objective is not to copy what is in the speaker's mind but to learn what might be of use to them—what is *relevant* to their evolutionary interests at the time.⁴ It is also the case that any given instance of mental reconstruction is likely to reflect the influence of prior reconstruction. Hence, we all have brains shaped by culture, and cultural filters determine any further shaping of our brains by experience.

Take the example of gossip, which is a major topic of human conversation (Dunbar 2004). One could think of it as trying to create shared opinions about third parties, as coming to an agreed assessment of the character of others not present. One may not create the same opinion of a third party in the listener but merely influence that person's opinion upward or downward. In any case, why invest so much time trying to convince someone of the trustworthiness of others? Presumably to boost one's own relative social standing (as the source of valuable information) and/or to cause the listener to engage in—or refrain from engaging in—a variety of behaviors, either with oneself or the subjects of gossip.

Human communication is unlike that of other species because we are not interested in decoding the meaning of what has been said. In a sense, we don't care about content. At least the chain of inferences prompted by the perception of social signals doesn't stop there. We proceed to figuring out what the speaker was trying to achieve by communicating that content, to us, in that situation (in essence, Grice's notion of "implicature") (Grice 1991). This is why pragmatics, or the study of language in use, must complement semantics, or the study of meaning, to understand human communication. Communication is about changing the minds of others, not transferring informational content (Sperber and Wilson 1995; Taillard 2005).

DISCUSSION

A variety of positions can be, and have been, taken with respect to the nature of information transmission in cultural change. Most contemporary scholars see some form of social learning as central to cultural change (contra the “innatists,” who argue that culture is just another aspect of genetic phenotype). However, the mechanism by which social learning occurs remains more or less vague in most accounts. This leads to problems when the objective is to describe or predict the consequences of social learning: cultural change.

While I do not provide new insight here into the mechanisms of social learning underlying cultural change, I have been concerned with the role of communication, as a form of social niche construction, in cultural change. Because the various positions outlined here are typically not explicit about the means of transmission, it is difficult to evaluate whether their claims about cultural dynamics involve intentional communication or whether they could be restricted to inadvertent transmission pathways. I will therefore leave this issue aside and only pursue the question of what cultural dynamics would be like if based in communicative events.

Communication is typically seen as fairly instantaneous message passing, with little role given to the environment (except in the form of a channel). However, with the advent of technology, it is possible for the environment to store information for later acquisition by human beings. I have suggested that social learning needs to be placed in a broader context when dealing with humans, due to their ability to involve artifacts in the learning process. Transmission in the sense of the active, simultaneous exchange of information between sender and receiver is therefore not a sufficiently general model of communication to sustain investigations into cultural change. It places the emphasis in the wrong place: on the context of individual message transfers. To be interesting, culture should be thought of as the consequence of many chains of communication, resulting in a population of stored messages.

The advantage of this “cultural constructionist” position is that it then becomes possible to deal with communication in modern societies using the same model as applied to “standard” face-to-face communication. It also illuminates the fact that even nontechnological communication is a niche-constructive activity. This is because communication is *always* “mediated” by signaling, even in the simplest species. Signals are physical things. The social insects, for example, use a variety of chemicals to communicate with one another.

Leaving pheromone trails may not be the image most social scientists have in mind when considering cultural transmission, but neither is typing an e-mail into one computer and having the message being read days later by someone half a world away. The standard model of transmission—speech in the context of a face-to-face interaction—may be a rather rare form of communication when viewed from a phylogenetic perspective and from a human historical perspective as well. In the future, it is likely to become even less familiar as a mode of human communication, as technologically mediated communication becomes even more prevalent than it is today.

To understand culture, we have to be able to follow messages as they wend their way through various forms between sending and receiving people. Nowadays, information is spending more and more of its time in artifacts. Indeed, cultural change is being increasingly influenced by a progressive trend in the nature of communicative processes: mediation by artifacts. The use of artifacts to mediate communication has a long history. For example, chimpanzees use leaf clipping (a particularly loud means of ripping leaves with the fingers or mouth) to communicate various kinds of messages. In some groups, leaf clipping signals a desire for a mating; in others it indicates an individual’s frustration with the current situation; in yet others, it is absent, suggesting the same use of an artifact (the leaf transformed into artifact by ripping) has culturally specific meanings in each group (Whiten et al. 1999). Humans

have obviously taken such practices to much greater lengths. Indeed, much of human behavior has been sucked into artifacts used as communication channels. Perhaps the most extreme contemporary example is online virtual worlds like Second Life, in which people can spend their time supervising avatars as they engage in all significant human activities (including economic and sexual exchanges) with the avatars of other players in a synthetic environment visualized via computer terminals. By allowing people to come together in synthetic environments or in common spaces such as Friends Reunited, MySpace or Facebook (various social networking Web sites), who knows whom is no longer determined by physical proximity but rather by shared interests. This constitutes a fundamental reorganization of social structures that surely has an impact on the dynamics of cultural change.

Whether to count the information stored in the environment as part of culture proper becomes a major question in this case. I have previously argued that it should not. (Aunger 2002) The practical reason is that it makes it harder to conceptualize or measure cultural “alleles” and their frequencies because the population must be defined in terms of people-plus-artifacts rather than just people. A theoretical reason is that if information inheritance is occurring *within* the technological domain, this will influence any dynamics that might be investigated in culture, and the dynamic interaction between mind-based culture and technological culture will itself coevolve over time. My argument is that this potentially independent dynamics of information inheritance, mutation, and selection in artifact populations/networks, and its coevolutionary dynamic with mental culture, should be explicitly dealt with in cultural evolutionary studies—at least where there is significant involvement of symbolic artifacts in a society’s culture (Aunger 2002, 2006).

We have, in a way, returned to the position of the evolutionary psychologists here: transmission per se is not an adequate model of cultural change. Instead, attention must be paid to other

possible sources of information besides social learning. However, there are two significant differences between my position and that of the evolutionary psychologists. First, what can be called “cultural constructionism” emphasizes that much of individual learning is with respect to artifacts produced by others, rather than an exogenous environment, so it remains social learning, if only in an indirect sense. Second, constructionism stresses the importance of population-level consequences from repeated chains of transmission events, which evolutionary psychologists and behavioral ecologists tend to downplay. The cause of cultural stability is not genetic assimilation, as the evolutionary psychologists would have it, but, rather, the stabilizing influence of enduring informational infrastructures in modern societies that play a significant role in mediating human interactions, cultural and otherwise.

In the end, use of the word *transmission* to describe this complex process of technologically mediated social learning may be counterproductive. Transmission is linked to the idea of information, which tends to have a rather abstract, disembodied quality. It also allows one to be sloppy about specifying a mechanism. Perhaps the word *transfer* is preferable, as it suggests the existence of a physical object that must be moved from one place to another. It also reduces the possibility of thinking that information is something with no mass or energy that can be conveyed to naive individuals without loss of the original “message” or cost in the transfer. In fact, work must be done to cause the duplication of information, just like anything else. This effortful activity will only take place when it is in the evolutionary interest of the communicator.

I have argued this interest in communication is most likely to be reflected in the goal to make conspecifics change behavior in specific ways that are advantageous to the communicator. Such communicative intentions are likely to be effective when the interests of the receiver overlap with those of the communicator, as is the case within families (e.g., skill transfer)—a context likely to have been significant in evolutionary terms.

Communication can be achieved through the creation of signal templates or data that are stored in artifacts for later connection to receivers. In any case, communication requires construction. Models of the communication process that ignore the physical requirements of information transfer are inadequate, and approaches to cultural evolution that ignore the possibilities of information storage, inheritance, and mutation through machine networks are also incomplete. Cultural evolution is best studied as a coevolutionary, *coconstructive* process in both organic and inorganic lineages.

Cultural constructionism has a number of advantages over the other metaphors used to describe cultural change described here. It is strategic in its treatment of communicative agents; it is physicalist in the sense that it specifies the activities associated with communication, rather than thinking of communication as an abstract or “magical” process; it explicitly acknowledges the role of technology in communicative acts; it is evolutionary and therefore allows culture to accumulate. Perhaps most importantly, it unifies the treatment of all forms of human communication under a single model, as a process of signal production, consumption, and consequent behavior.

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NOTES

1. Information is not typically considered to be subject to the constraints of matter and energy conservation; however, the physics of information suggest that information is a kind of form and cannot be created without energy. Information always has a physical substrate, and its creation is a negentropic act (Landauer 1991; Bennett 1995).
2. Teaching or other forms of instruction are designed to reproduce information, ideas, or beliefs. However, this is a specialized kind

of communication. Education of the young is a cooperative endeavor, traditionally engaged in by kin, who share genetic interests. But more generally, communication is manipulative in nature due to the conflicts of interest between the senders and receivers of signals or messages.

3. However, if most cultural transmission occurs outside the context of communication, and hence is inadvertent, then mechanisms of imitation could be favored by selection. In this case, memes might exist—they just wouldn’t replicate through intentional communication, as most memeticists insist (Blackmore 1999; Dawkins 1976).
4. This is not to deny that high-quality replication doesn’t sometimes occur as a result of communication, only that it is not the evolved function of such acts and so therefore may not occur often.

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FOUR

Modes of Transmission and Material Culture Patterns in Craft Skills

Robert Hosfield

THE TRANSMISSION of knowledge, teaching and learning mechanisms, and the role of social learning in determining what is transmitted have been extensively considered in recent years. Studies have explored primate tool use and behavior (e.g., Boesch 1993; Boesch and Boesch 1993; Whiten 2000), cultural traditions and variations (e.g., Boyd and Richerson 1985; Cavalli-Sforza and Feldman 1981; Guglielmino et al. 1995; Shennan 2002; Shennan and Steele 1999), and the nature of transmission and learning (e.g., Boyd and Richerson 1988; Rowlands 1993; Tindall 1976). These studies have highlighted both the complexities of learning and knowledge transmission processes, and their implications for what humans learn and how they learn it, and therefore their short- and long-term impacts on human behavior and material culture.

This chapter explores the topic of knowledge transmission and learning with regard to craft skills: the acquisition of craft knowledge, patterning in material culture, and the detection of modes of transmission on the basis of material culture patterning in the archaeological record. The observations of Shennan and Steele

(1999, 376) and Shennan (2002, 49) that transmission relating to the learning of craft techniques appears to be mainly if not entirely vertical/oblique rather than horizontal are tested against an expanded data set (ethnoarchaeological, archaeological, and ethnographic), and the impacts of these modes of transmission are explored with respect to the degree of conservatism or innovation seen in the resultant material culture products. The chapter concludes by exploring how improved understanding of the processes of craft skills learning can assist in the interpretation of material culture patterning in the archaeological record.

CASE STUDIES

Seventy-two case studies provided data on both the mode of transmission associated with craft skills learning and the nature of the material culture patterning. In a number of instances (e.g., for the Hidatsa of North Dakota [Bowers 1965] and the Kalinga of the Philippines [Longacre 1981; Stark and Longacre 1993]), two cases were derived from a single group or culture, as distinctions were made between the varied impacts

of vertical transmission and horizontal transmission on material culture. The case studies were collated from a wide range of sources, including the Human Relations Area Files (HRAF) databases for ethnography and archaeology (HRAF 2002; table 4.1). Selection was based on the documentation of both the mode of cultural transmission and material culture patterning.

MODES OF TRANSMISSION

The modes of cultural transmission defined by Cavalli-Sforza and Feldman (1981), and since reused by a number of other authors (e.g., Hewlett and Cavalli-Sforza 1986, 923–924, figure 1; Shennan 2002, 48–51, figure 4), formed the basis for classifying and identifying the routes of craft skills learning in the case study literature:

- Vertical (parent-to-child): the closest to biological transmission; highly conservative and likely to result in slow cultural evolution. Shennan and Steele (1999, 376) observed in their survey of craft techniques learning that vertical transmission commonly occurs between parents and same-gender offspring.
- Oblique: no genetic parallel; involves learning from nonparents of the older generation (Shennan 2002:49)
- Master/apprentice (a specialist subset of oblique transmission): the division drawn here between oblique and master/apprentice transmission reflects the evidence in the case study literature for the distinctive conditions and circumstances associated with craft apprenticeships (e.g., the removal of individuals from their homes and their relocation within the master's house (Epstein 1998, 688–693; Silver 1981, 43–44).
- Horizontal (peers, individuals from other communities/social units, foreign traders): Cavalli-Sforza and Feldman (1981) viewed this as a typically “cultural” form of transmission, occurring between two individuals within the same generation, in which individuals learn from their contemporaries.

A limitation of the data sources concerned their frequent failure to distinguish between vertical, oblique, and master/apprentice modes of transmission. Van der Grijp's (1995) investigations of basket making and mat weaving on Tonga noted that girls learn these skills at school (Hewlett and Cavalli-Sforza's [1986, 924] one-to-many transmission) but that they also learn the finer points of the crafts from experienced sisters and aunts (oblique transmission) and mothers (vertical transmission). No distinction was drawn between these different teaching and learning models; and although it may be that, for example, the maintenance of traditions was emphasized by all of the transmitters, this is unknown. These data limitations were also sometimes evident with regard to distinctions among vertical, oblique, and horizontal transmission. For example, Navajo weaving was learned from parents and aunts (vertical and oblique transmission), but there was also a considerable history of borrowing and modifying traits (e.g., weaving patterns) from neighboring cultures (horizontal transmission) (Downs 1972; Kent 1985; Kluckhohn 1946; Newcomb 1964). Nonetheless, the available data generally supported Shennan and Steele (1999, 376) in that 73.6 percent ($n = 53$) of cases consisted of vertical, oblique, or master–apprentice modes of transmission (or some mixture thereof).

IDENTIFYING EVIDENCE FOR CONSERVATISM AND INNOVATION IN MATERIAL CULTURE

Unfortunately, it was extremely rare to find detailed data regarding the degree of conservatism/innovation involved in the learning and practice of particular crafts (e.g., data illustrating the changing frequencies of material culture types over time). Consequently, it was necessary to base inferences concerning the degree of conservatism on a number of lines of evidence.

The documentation of distinctive material culture types at the level of individual social units, in comparison with surrounding units, was interpreted as evidence for conservative practices and the maintenance of traditions. This approach follows Longacre's (1981, 61–63)

TABLE 4.1. *Case Studies and References*

CASE STUDIES	REFERENCES
Africa	
Aka , Central African Republic	Hewlett and Cavalli-Sforza (1986)
Asante, Bonwire, Ashanti, and Ewe, Ghana	Lamb (1975); Rattray (1927)
Igbo, Iseyin, Ooko, Yoruba, and Zaria, Nigeria	Allen (1983); Bray (1969); Lloyd (1953); Nicholls (2000); Ottenberg (1975); Roy et al. (2000)
Kalahari San, southern Africa	Wiessner (1983)
Kisi, Tanzania	Kramer (1985); Waane (1977)
Lozi, Zambia	Hodder (1981)
Maghreb, North Africa	Balfet (1981)
Moba, Togo	Kreamer (2000)
Toumra, Darfur, Sudan	Haaland (1985)
Wolayta, Ethiopia	Silverman (2000)
Zaghawa, Kebkebiya, Sudan	Tobert (1985)
Asia	
Iban, Sarawak, Malaysia	Mashman (1991); Sandin (1980)
Ifugao, northern Luzon, Philippines	Centre for Women's Resources (Philippines) (1999); Kok (1979); Lambrecht (1958); Tolentino (2001)
Kalinga, Philippines	Kramer (1985); Longacre (1981); Stark and Longacre (1993)
Khambhat, India	Roux et al. (1995)
Rajasthan, India	Kramer (1997)
Sherpa, Nepal	Brower (1987, 1991)
Thimi and Bhaktapur, Kathmandu Valley, India	Birmingham (1975)
Vijayanagara, India	Sinopoli (1988)
Australasia and Pacific Islands	
Alyawara, central Australia	Binford and O'Connell (1984)
Arnhem Land, northern Australia	Jones and White (1988)
Nakauvadra, Fijian Islands	Tippett (1968)
Samoa	Mead (1928)
Telefol, central New Guinea	Ingold (2000); MacKenzie (1991)
Tikopia, western Polynesia	Firth (1939)
Tonga, western Polynesia	Van der Grijp (1995)
Trobriand Islands, New Guinea	Scoditti (1982, 1990)
North and Central America	
Klamath, California and Oregon, USA	Barrett (1910); Pearsall (1950)
Hawaiian Islands, USA	Handy (1972)
Amatenango, Chanal, Aguacatenango, Chamula, and San Mateo Ixtatan, Mayan Highlands, Mexico and Guatemala	Deal (1998); Hayden (1987); Hayden and Cannon (1984); Hayden and Nelson (1981); Howry (1978); Nash (1970); Nelson (1987)
New England, USA	Clarke (1939)
Zuni, New Mexico, USA	Adair (1945)
Mandan and Hidatsa, North Dakota, USA	Bowers (1950, 1965)
Huichol, northern Mexico	Deal (1998); Zingg (1938)
Atzompa, Oaxaca, Mexico	Deal (1998); Hendry (1992)
Otomi, Pino Suárez, Mexico	Aronson and Fournier (1993)
Hopi and Hopi-Tewa, Navajo, and San Carlos/ Western Apache, southwestern USA	Adair (1945); Deal (1998); Downs (1972); Ferg (1987); Ferg and Kessel (1987); Goodwin (1942); Hartman (1987); Hurt (1942); Kent (1985); Kluckhohn (1946); Newcomb (1964); Perry (1991); Roberts (1929); Stanislawski (1977, 1978); Stanislawski and Stanislawski (1978); Tschopik (1941)
Zapotec, Yulálag, Mexico	Jopling (1977)
South America	
Shipibo-Conibo, Peru	DeBoer (1984); DeBoer and Lathrap (1979)
Yamana, Tierra del Fuego, Chile	Dransart (1992)

detection of microtraditions (reflecting vertical, mother–daughter transmission) and distinctive village styles among the Kalinga of northern Luzon in the Philippines. While such patterns could also reflect independent experimentation and innovation within the individual social units, combined with a lack of horizontal transmission, such experimentation might be expected to result in at least partial duplication and overlap of styles, forms, and/or techniques among different units. The units could be individual households (e.g., Bowers 1965), lodges (e.g., Bowers 1950), compounds (e.g., DeBoer 1984), villages (e.g., Balfet 1981), or valleys (e.g., MacKenzie 1991). Anecdotal references to the maintenance of old styles or traditions (e.g., Deal 1998; Stanislawski 1977, 389–390, 1978, 214; Stanislawski and Stanislawski 1978, 63) or to experimentation and change in material culture (e.g., Deal 1998, 26–37; Kent 1985) were interpreted as evidence for conservatism and innovation, respectively. Comparisons (anecdotal, typological, or quantitative) between modern materials and historical/archaeological assemblages (e.g., DeBoer 1984, 557; Hurt 1942, 94–95; Nash 1970, 48–49) also provided evidence for either conservatism or innovation. References to social practices or traditions (e.g., production secrets, access to manufacturing rights and related knowledge; Bowers 1950; MacKenzie 1991, 104–106), or social attitudes toward innovation and change (e.g., Hayden 1987; Kent 1985; Mead 1928), were interpreted as evidence for conservatism or innovation as appropriate. In the case of social attitudes, there were often clearly defined pro- (e.g., Kent 1985; Mead 1928) and anti-innovation stances (e.g., Hayden 1987). The maintenance of production secrets among selected individuals within a community or craft production unit was commonly only associated with the maintenance of traditions, rather than with innovation and change. Finally, references (anecdotal or documented) to new forms, styles, designs, decorations, and/or techniques in material culture (e.g., Aronson and Fournier 1993; Nicholls 2000; Stark and Longacre 1993) provided evidence for innovation.

Given the nature of the data just described, only two basic categories for material culture patterning could be defined: conservatism ($n = 46$, 64 percent; defined as the maintenance of traditions and/or little evidence of change in material culture) and innovation ($n = 26$, 36 percent; defined as experimentation and/or the introduction of new traits in material culture). Since the key goal of the chapter is to explore the relationships between modes of transmission and material culture patterning, it was also desirable to further split the innovation cases ($n = 26$) into experimentation ($n = 12$, 46 percent; defined as the independent invention of new traits) and borrowing ($n = 14$, 54 percent; defined as the external introduction of new traits and therefore automatically associated with the horizontal mode of transmission). The innovation category (and subcategories) also makes no distinction between the types of possible changes in material culture, although it was evident that changes included new types or forms (e.g., Nicholls 2000), new designs (e.g., Lamb 1975), patterns (e.g., Ottenberg 1975) or decorations, and new techniques and practices (e.g., Hayden 1987). In many cases, either these data were not specified, or data distinguishing between multiple types of changes were not available (e.g., Stark and Longacre [1993] discuss in general terms the appearance of new forms, decorations, and styles in the pottery of the Kalinga during the 1970s and 1980s).

CRAFT SKILLS

For the purposes of this chapter, *craft skills* are defined as those motor and cognitive skills required for the production of end products through the manipulation of raw materials by the use of tools, including the human hand (after Roux, Bril, and Dietrich, 1995, 63; Robertson 1961, 27). The case studies' end products could either be for domestic use or sold through a non-domestic setting (e.g., a marketplace), while the raw materials and end products are all characteristic of (although not necessarily restricted to) preindustrial societies. The key craft skills identified in the case studies were pottery, weaving, lithics (stone tool production, including the

production of glass artifacts using lithic knapping techniques), carving, and metalworking.

ANALYSES AND RESULTS

Because of the nature of the data described here, only nominal or ordinal-scale variables were appropriate in most cases (the test variables and data categories are summarized in table 4.2). Therefore, contingency tables were constructed, based on cross-tabulation between appropriate variables. χ^2 analyses were applied to the data, reflecting the nominal and ordinal-scale data categories (table 4.3). This enabled an exploration of the possible relationships between the modes of transmission associated with craft skills learning, patterns in the material culture, and a range of other variables. The significance level (α) for all of the χ^2 tests was 0.05.

The key results of the analyses were as follows.

TRANSMISSION MECHANISMS

Mode of Transmission versus Degree of Conservatism; Mode of Transmission versus Innovation Type.

A significant association ($p = 0.000$, Cramer's $V = 0.683$; table 4.3) was demonstrated between (1) vertical (parental) transmission and conservative patterns in craft skills' material culture and (2) horizontal transmission and innovative patterns in craft skills' material culture. Transmission through teachers or craft masters (i.e., apprenticeship systems) was associated with a mixture of both innovative (all through experimentation) and conservative patterns in material culture, although a very small sample size ($n = 7$) is noted here. With regard to the different types of innovation, significant associations ($p = 0.000$, Cramer's $V = 0.926$; table 4.3) were evident between vertical, master-apprentice, and mixed (vertical, oblique, and/or master-apprentice) transmission and innovation by experimentation, while innovation by borrowing was predominantly (and unsurprisingly) limited to horizontal transmission (for which there was only one example of

innovation by experimentation). There was little evidence for innovation by borrowing occurring among artisans whose learning of their craft was vertical or oblique.

Where vertically transmitted craft skills were associated with material culture innovations (predominantly through the "mixed" categories), these patterns often reflected local, context-specific attitudes encouraging experimentation. For example, at Thimi and Bhaktapur in the Kathmandu Valley, India, potter knowledge is acquired by boys from their fathers, through vertical (parental) transmission. However, "there is no cultural pressure against innovation, in fact the reverse", and the potters consciously select from a very wide range of technical skills and use them "adventurously," resulting in a tradition of innovation in local pottery production (Birmingham 1975, 381). In Chanal in the Mayan Highlands, new potters developed their own style over time, often resulting in very little resemblance between their work and that of their teachers, who were most commonly their mothers (Deal 1998, 27).

DIFFERENT CRAFT SKILLS

Craft Skill Type versus Degree of Conservatism.

The different skills were not significantly conservative or innovative (table 4.3), although the data did suggest conservative trends in lithic material culture and the possibility of innovative approaches to metalworking. Classifying the crafts according to whether they were additive or subtractive (Craft Skills Reclassed vs. Degree of Conservatism) likewise did not produce a significant result (table 4.3), and there was also no clear evidence that specific crafts were associated with specific modes of transmission (Mode of Transmission vs. Craft Skill Type; Mode of Transmission vs. Craft Skills Reclassed; table 4.3): in other words, all of the craft skills were learned in a variety of different ways.

These patterns are not especially robust, but, first, they may reflect the absence of surface decoration and/or design patterns on lithics. Four of the six examples of innovation in basketry and weaving concern changes in designs, four of the

TABLE 4.2. *Data Variables and Categories*

VARIABLE	CATEGORIES	COMMENTS
Mode of transmission (V01)	1. Vertical 2. Oblique 3. Master/apprentice	4. Mixed ¹ 5. Horizontal 6. Mixed ² Mixed categories include some/all of vertical, oblique, and master/apprentice (<i>Mixed</i> ¹) and some/all of vertical, oblique, master/apprentice and horizontal (<i>Mixed</i> ²). See “Modes of Transmission” in text for further details.
Degree of conservatism (V02)	1. Conservatism	2. Innovation See “Identifying Evidence for Conservation and Innovation in Material Culture” in text for further details.
Innovation type (V03)	1. Experimentation	2. Borrowing See “Identifying Evidence for Conservation and Innovation in Material Culture” in text for further details.
Craft skill type (V04)	1. Pottery 2. Weaving and basketry 3. Lithics and stoneworking	4. Wood carving 5. Metalworking 6. Other <i>Lithics</i> category includes glassworking using lithic knapping techniques. <i>Other</i> category includes craft skills not covered elsewhere, references to generic craft skills, and cases with multiple, undistinguished craft skills.
Craft skills reclassified (V05)	1. Additive 2. Subtractive	3. Generic (specific craft skill data not available) Categories defined by addition (pottery, weaving, metalworking) or subtraction (lithics, woodcarving) of raw materials during manufacturing.
Social pressures? (V06)	1. Yes	2. No Social pressures against innovation (yes/no)?
Frequency of production (V07)	1. All-year round/daily/full-time 2. Seasonal/part-time	<i>Mixed</i> category is a combination of some/all of the other categories.
Length of learning (V08)	1. <1 year 2. 1–5 years	3. 5–10 years 4. 10+ years ——
Number of production stages (V09)	1. 1–5 stages 2. 6–10 stages	3. 10+ stages Given the limitations of the data, it is probable that the stated number of production stages is a <i>minimum</i> estimate.
Number of distinct artifact types (V10)	1. 1 type 2. 2–10 types	3. 10–25 types 4. 25 types + Data were based on the number of distinct types listed in the case studies and may be consistently underestimated.

Same sex? (V11)	1. Yes (females) 2. Yes (males)	3. No (females and males) 3. Mixed	Whether the transmitter and transmittee were the same or different (<i>No [females and males]</i>) sex.
Type of material culture change (V12)	1. Type, forms, designs, patterns, and decorations 2. Technologies, tools, and techniques of production		<i>Mixed</i> category is a combination of both of the other categories.
Observation time scales (V13)	1. <50 years 2. 50–100 years	3. 100+ years	Data based on dates and semiquantitative references (e.g., “three generations of change”).
Settlement type (V14)	1. Mobile campsite 2. Hamlet 3. Village	4. Town 5. Village/town	Incorporating variations in settlement size, community structure, and economic organization (e.g., the presence/absence, size, and function of markets).
Subsistence economy (V15)	1. Agriculture 2. Hunting-gathering	3. Mixed	Incorporating variations in material culture and economic/social structures. <i>Mixed</i> is a combination of both of the other categories.
Kinship/residence (V16)	1. Matrilineal/matrilocal	2. Patrilineal/patrilocal	Assessing impacts of residence patterns on learning frameworks.
Continent (V17)	1. Americas 2. Africa	3. India 4. Australasia and Pacific	_____
Latitude (V18)	1. Tropical	2. Nontropical	Defined by location between Tropics of Cancer/Capricorn (<i>Tropical</i>) and north/south of the respective tropics (<i>Nontropical</i>).

TABLE 4.3. *Summary of χ^2 Analyses*

TEST VARIABLES		SAMPLE SIZE (N)	P-VALUE	CRAMER'S V
Mode of transmission (V01)	Degree of conservatism (V02)	72	0.000	0.683
Mode of transmission (V01)	Innovation type (V03)	26	0.000	0.926
Craft skill type (V04)	Degree of conservatism (V02)	72	0.511	0.244
Craft skills reclassified (V05)	Degree of conservatism (V02)	72	0.781	0.083
Mode of transmission (V01)	Craft skill type (V04)	72	0.118	0.305
Mode of transmission (V01)	Craft skills reclassified (V05)	72	0.143	0.319
Social pressures? (V06)	Degree of conservatism (V02)	18	0.004	0.671
Mode of transmission (V01)	Social pressures? (V06)	18	0.639	0.375
Frequency of production (V07)	Degree of conservatism (V02)	32	0.508	0.270
Length of learning (V08)	Degree of conservatism (V02)	24	0.758	0.222
Number of production stages (V09)	Degree of conservatism (V02)	19	0.138	0.456
Number of distinct artifact types (V10)	Degree of conservatism (V02)	27	0.542	0.282
Same sex? (V11)	Degree of conservatism (V02)	68	0.629	0.117
Mode of transmission (V01)	Same sex? (V11)	68	0.059	0.362
Craft skill type (V04)	Type of material culture change (V12)	26	0.001	0.749
Craft skills reclassified (V05)	Type of material culture change (V12)	26	0.050	0.427
Mode of transmission (V01)	Type of material culture change (V12)	26	0.614	0.348
Observation time scales (V13)	Type of material culture change (V12)	11	0.268	0.486
Observation time scales (V13)	Degree of conservatism (V02)	21	0.013	0.645
Settlement type (V14)	Degree of conservatism (V02)	67	0.273	0.277
Subsistence economy (V15)	Degree of conservatism (V02)	61	0.138	0.456
Kinship/residence (V16)	Degree of conservatism (V02)	12	0.408	0.239
Continent (V17)	Degree of conservatism (V02)	26	0.900	0.090
Latitude (V18)	Degree of conservatism (V02)	72	0.274	0.129

NOTE: Statistically significant results, at $\alpha = 0.05$, are highlighted.

eleven pottery examples include innovative decorations, and all four examples of innovation in metalworking (silversmithing) are in design and decoration. Surface design and decoration may be a more easily identified form of innovation on craft items, although it is clear that there can be a marked contrast between the perspectives of the archaeologists/anthropologists and the producers: "Some forty-five or fifty Hopi decorative types (in the archaeological sense) could be calculated at a minimum; but they do not mean much, in behavioral terms, to the Hopi, who consider such technological factors as coiling, molding, scraping, smoothing, and firing to be vital, but see decoration, rim form, and the like as relatively unimportant matters of personal choice" (Stanislawski 1978, 215).

Second, of the six metalworking cases, four are from the American Southwest (silversmithing), and three of these four cases provide examples of innovation (including two by borrowing). The case studies indicate the impact of external, rather than domestic, market demands and document the production of new products for European markets (Adair 1945; Kluckhohn 1946). The trend toward innovation in metalworking in these cases may therefore represent, at least in part, external market factors.

SOCIAL PRESSURES AND ACTIVE CORRECTIONS/SANCTIONS

Social Pressures? versus Degree of Conservatism.

Unsurprisingly, there is a marked relationship ($p = 0.004$, Cramer's $V = 0.671$; table 4.3)

between innovation (through both experimentation and borrowing) in craft skills and social attitudes in favor of experimentation and innovation. More interestingly (and while acknowledging the sample size), the different social pressures are distributed across the vertical, master–apprentice, and horizontal modes of transmission categories (Mode of Transmission vs. Social Pressures?; table 4.3), suggesting that the presence/absence of such potentially important social pressures (with regard to craft skills development) cannot be predicted on the basis of the dominant mode of transmission and may even act semi-independently of the prevalent learning and teaching mechanisms. By contrast, six of the seven examples of sanctions and active corrections were associated with conservatism in craft skills (and five examples occurred within vertical [parental] and/or oblique [elders] transmission); unsurprisingly, this suggests that their presence is most commonly associated with the maintenance of existing traditions and “accepted” ways of working.

CRAFT SKILL DIFFICULTY

Length of Learning versus Degree of Conservatism; Number of Production Stages versus Degree of Conservatism; table 4.3.

The variation between conservatism and innovation in craft skills was considered in terms of the difficulty of learning and executing the craft skills, and the possible impact of variable difficulty levels on the inclination or ability to innovate. Assessing these difficulty levels from the case studies was not straightforward, and two proxy measures were adopted: the length of the learning phase (or phases) and the number of individual production stages (i.e., the number of distinct processes that needed to be learned). No significant patterns were evident in the data when using either proxy, although this may reflect limitations in this data set, as previous studies (e.g., Roux 1990, 143–145 and figure 2; Roux et al. 1995, 78–81) have highlighted relationships between the length of time spent learning and the complexity of the motor skills to be acquired. In this regard, it is perhaps interesting that the only examples of innovation in

the data set used here (for which production stages data were available) were associated with the shortest number of production stages category: stoneworking in the Maya Highlands (Hayden 1987; Nelson 1987), weaving in Bonwire, Ghana (Lamb 1975), and pottery in Thimi and Bhaktapur, Kathmandu Valley, India (Birmingham 1975). Nonetheless, the absence in this study of significant associations between craft skill difficulty and conservatism/innovation may also follow previous work by Roux et al. (1995, 81–83) and Dietler and Herbich (1998, 161), which noted that very high (Roux et al.) or low (Dietler and Herbich) levels of individual expertise, rather than the general craft difficulty, were a key factor in promoting innovation.

CRAFTSMEN AND CRAFTSWOMEN

Same Sex? versus Degree of Conservatism; Mode of Transmission versus Same Sex?; table 4.3.

In the majority of cases (98 percent) where the necessary data were recorded ($n = 40$), teacher and learner were the same sex, confirming the observations of Shennan and Steele (1999, 376). There were no significant conservatism/innovation patterns in the male/female data or any significant contrasts between the sexes with regard to the modes of transmission associated with their craft skills learning.

TYPES AND TIME SCALES OF CHANGE IN MATERIAL CULTURE

Craft Skill Type versus Type of Material Culture Change; Craft Skills Reclassed versus Type of Material Culture Change; Mode of Transmission versus Type of Material Culture Change; Observation Time Scales versus Type of Material Culture Change; Observation Time Scales versus Degree of Conservatism; table 4.3.

Types, forms, patterns, and decorations ($n = 20$) and the techniques and technologies of production ($n = 5$) were all used to identify change or similarity in the case study materials, raising three questions:

- Do technical changes occur less frequently in certain craft skills, and are they therefore

underrepresented in the case studies reported here?

- Are the techniques and technologies of craft production inherently stable (or at least more stable than the designs and forms of the end products)?
- Are ethnographic, ethnoarchaeological, and anthropological studies biased against the recording of technical changes in craft production?

The analyses suggested that certain types of material culture change do occur less or more frequently in different craft skills ($p = 0.001$, Cramer's $V = 0.749$; $p = 0.050$, Cramer's $V = 0.427$; table 4.3), with changes in forms overrepresented among the weaving, carving, and metalworking crafts, while technical changes were overrepresented in the lithics and pottery crafts. However, since these two groups represent 54 percent (pottery and lithics) and 38 percent (weaving, carving, and metalworking) of the case studies, it would appear that the apparent association between technical changes and pottery/lithic crafts does not explain the former's generally low presence (20 percent of all types of change) in the case study data. Technical innovations also occurred in association with vertical, master-apprentice, and horizontal transmission, suggesting that while technical processes might be more stable than other types of material culture change (but see comments later), they can occur internally and do not always require horizontal transmission for their introduction (i.e., they are associated with innovation by both borrowing and experimentation).

Although the overall data suggest that technical changes are far less common than other types (e.g., changes in forms and patterns), it is possible that this represents problems of data collection. The duration of many research studies and field projects means that unless past techniques can be reconstructed from preserved artifacts or the tools used in manufacture, or from oral records, there is often no way of comparing contemporary, observed techniques with those from the past (although an increasing number of

studies are successfully exploring and comparing technical variability; e.g., Gosselain 1992, 2000; Dietler and Herbich 1989, 1998; Roux et al. 1995). By contrast, comparisons of material culture can be made on the basis of preserved artifacts (including museum collections and historical illustrations or documents). There is also a lack of consistency in the case studies used in this study with regard to what is classified as conservatism/stability in material culture and what is seen as innovation.

Interestingly, innovation cases are overrepresented in the shortest time scale category, with conservatism cases overrepresented in the middle and longer of the three categories ($p = 0.013$, Cramer's $V = 0.645$; table 4.3). These patterns may reflect the way the cases were described however, since examples of conservatism in the case studies were often based on nonspecific references to old "traditions" (e.g., from the previous century) or generic material culture comparisons. For example, van der Grijp (1995) argues that tapa producing techniques on Tonga have remained unchanged for centuries (although without including any direct comparisons of techniques); Allen (1983, 165) notes that the potters of Zaria, Nigeria, "have a skill that has been passed down over many generations in a relatively unchanged form as far as actual techniques are concerned"; and Kramer (1997, 169) makes reference to historical and archaeological assemblages when arguing that the modern Rajasthani potters produce vessels bearing stylistic and technological features stretching back millennia. By contrast, examples of innovation in the case studies are often based on specific material culture comparisons over shorter time scales, for which explicit data are available, or on anecdotal memories. For example, Hendry (1992) refers to the recent proliferation of pottery innovations at Atzompa, Mexico, over the previous fifty years, while Hayden (1987) documents the introduction of metal stoneworking tools and new techniques of quarrying into the stone tool production and metate manufacturing traditions of the Maya Highlands, Guatemala,

over fifteen to twenty years (based on interviews with a local stoneworker).

Different time scales of observation may therefore have a significant impact on the classification of material culture patterns as either conservative or innovative. Among the Igbo in Nigeria (Nicholls 2000), girls learned pottery production from their mothers, and “traditional” methods were used. More recently, however, some of the villagers had been temporarily employed away from the village, in town-based Western factories, where they had learned to produce new forms. Upon the villagers’ return to the villages, these new forms were introduced and produced alongside the traditional forms. Moreover, these new forms were also adopted by those potters who had never worked in the factories. The key point is that over the time scales of Nicholls’s study and observation, innovation (of new pottery forms) has clearly occurred through horizontal transmission (borrowing via the factory). It is interesting to speculate, however, whether over two hundred years, and based on a fragmented and chronologically sporadic sample, one would not be inferring conservatism, since the traditional forms continued to be produced and would indicate at least *some* long-term traditions in pottery production.

ANALYSIS OF THE REMAINING VARIABLES

Tables 4.2 and 4.3.

This revealed no significant patterning.

DISCUSSION

Vertical (parental) and horizontal modes of transmission showed clear associations with conservative and innovative patterns in craft skills’ material culture, respectively. However, other modes of transmission (oblique and master–apprentice, and where different modes were indiscriminately combined in the case study literature) showed less clear patterns; both conservatism and innovation were represented. Innovation through borrowing was, unsurprisingly, strongly correlated with horizontal transmission, with innovation through experi-

mentation conversely associated with, and predominantly limited to, vertical, oblique, and/or master–apprentice transmission modes. There was only one example of horizontally transmitted innovation linked to experimentation and only one example (among the Navajo weavers) of artisans learning from their elders and also showing a history of borrowing traits from neighboring cultures.

There were relatively few distinctive associations between different craft skills and either patterning in material culture or the modes of transmission by which they were learned. In other words, particular craft skills were no more conservative or innovative than others (whether defined by type or as additive or subtractive craft skills), and the majority of the skills appeared to be learned through a variety of different transmission modes. However, the analyses also suggested the potential importance of other factors, including the case studies’ frequent reliance on design and decoration as a means of defining innovation and the role of market demands in craft innovation.

Social pressures, both pro- and anti-innovation, unsurprisingly showed strong relationships with, respectively, patterns of innovation (both experimentation and borrowing) and conservatism in material culture. However, it was apparent that these social pressures could not be associated with specific modes of transmission: for example, anti-innovation social attitudes and pressures were not solely associated with vertical (parental) transmission. In short, social pressures were hard to predict and required understanding of the specific cultures and contexts in which they existed. However, active corrections and sanctions were strongly associated with conservative patterns of material culture and were linked to vertical (parental) and/or oblique (elders) modes of transmission.

While the different types of material culture innovation (e.g., in decorations or techniques) do not appear to vary by craft type (within the restrictions of the available data), it is suggested that changes in techniques and manufacturing practice do appear to occur less frequently. However,

this may only reflect past difficulties of identifying such changes (e.g., in comparison with decorative changes in pottery) over the time scales of ethnoarchaeological studies, for example, and the limitations of some of the data used here. It should also be noted that an increasing number of recent and current studies (see earlier references) are continuing to improve the available data in this regard.

Overall, it is clear from the case studies and the analyses that conservatism and innovation in material culture are potentially related to more than the modes of transmission associated with craft skills learning. For example, Graves's (1981) analysis of pottery production among the Kalinga concluded that factors other than learning frameworks contributed to design variability, including the seasonality of production and the idiosyncratic tastes of the potter over time.

ARCHAEOLOGICAL IMPLICATIONS AND CONCLUSIONS

The results summarized here have a number of potential implications for the analysis of material culture evolution and patterning in the archaeological record. While it is nearly always impossible to directly reconstruct modes of transmission for craft skills learning in archaeological cultures (due to the common absence of written sources), the clear patterning in the analyses (vertical transmission/conservative; horizontal transmission/innovation by borrowing) does offer an alternative approach. An index of connectivity for a particular archaeological community/region/culture could reveal relationships with the relative conservatism/innovation observed over time in the craft skills' material record(s). This assumes, of course, that the index is a measure of the degree of external contacts and therefore of the potential for horizontal transmission (and borrowed/introduced innovations for example). Construction of the index would be challenging but could be based on settlement density values, the density of material culture variations, or regional interconnectivity (utilizing network

analyses). Variations to the predicted patterns should be considered in terms both of additional factors (as discussed earlier) and the potential impacts of other modes of transmission (particularly oblique, master-apprentice, and mixed modes of transmission).

Analysis of archaeological crafts should assume that different types are not more or less inherently conservative and/or innovative and that different crafts are not associated with specific modes of transmission with regard to skills learning, although the great majority of craft skills in general are transmitted through vertical and oblique modes. However, it is clear that consideration should be given to our definitions of innovation and to the relative frequency and ease of identification of similarities and changes in decorations and designs (e.g., in pottery and weaving compared with those in lithics) or technical practices, following recent studies such as Gosselain (2000) and Dietler and Herbich (1989, 1998), among others. Finally, consideration should also be given to the role of market demands (the proximity of markets may also be identifiable in the archaeological record).

Variables such as frequency of production, craft skill difficulty, and material culture variability can be demonstrated in the archaeological record (e.g., frequency of production was demonstrated in the work of Shafer and Hester [1986, 1991] regarding Maya stone tool production at Colha, while craft skill difficulty can be reconstructed from *chaîne opératoire* evidence [Edmonds 1990; Pigeot 1990]). However, the analyses reported here suggest that these factors do not appear to be important with regard to conservative or innovative trends in material culture patterning.

Social pressures, sanctions, and active corrections are, however, clearly an important factor with regard to material culture patterning, and evidence from the *chaîne opératoire* (e.g., the repetitive use of a single manufacturing "path" that was demonstrably not the most efficient option) and/or highly standardized end products could potentially be used to detect their presence in the archaeological record. This

final point also serves as a valuable reminder that all attempts to explore patterns in archaeological material culture from the perspectives described in this chapter must first consider the specific, local contexts of learning, production, and use (e.g., Deal 1998; DeBoer 1984; Kramer 1997; Stanislawski 1977), which are critical to our understanding.

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FIVE

Linking Pattern to Process in Cultural Evolution

INVESTIGATING MATERIAL CULTURE DIVERSITY AMONG THE NORTHERN KHANTY OF NORTHWEST SIBERIA

Peter Jordan

INCREASING NUMBERS of archaeologists and anthropologists are borrowing theory, models, and analytical methods from evolutionary biology in order to produce novel ways of understanding the emergence of cultural and linguistic diversity in different regions of the globe. Central to these investigations are long-standing interests in the processes by which traditions are passed from one generation to the next via a suite of social learning mechanisms that go on to generate larger-scale patterns of cultural evolution (Cavalli-Sforza and Feldman 1981; Boyd and Richerson 1985; Durham 1990, 1992; Shennan 2002).

The application of cladistics (Lipo et al. 2006b; Mace, Holden, and Shennan 2005, for recent overviews of the field) and other quantitative analytical methods is of particular importance because of the refreshing degree of empiricism (Bryant, Filimon, and Gray 2005) injected into the increasingly sterile debates about the *exclusive* validity of general models of macroscale cultural evolution (the “branching

trees” vs. “tangled banks” debate; see Collard and Tehrani 2005, 109–112, and Collard, Shennan, and Tehrani 2006, 53–55, for recent overviews with references). As a result, a growing body of analytical work is demonstrating that cultural evolution is characterized by *both* branching *and* blending patterns of “descent with modification,” each affecting diverse data sets in different ways (Collard et al. 2006, 62) and probably for very different reasons. Through time, the relative importance of branching and blending patterns of inheritance will generate quite different patterns of continuity and change across different domains of culture (see Boyd et al. 1997 for useful summary models).

Further research assessing the wider distribution of these general patterns of transmission will add to these general insights. However, more studies could take their analysis beyond this “mapping stage” and attempt to *explain* how certain processes are generating specific distributions of cultural similarities and differences among social groups and why. Such studies of

“cultural transmission in action” would ideally involve more detailed investigation into how particular forms of interaction, demography, social learning and subsistence practice interact with one another to structure transmission processes and generate observed *patterns* of cultural diversity (see Tehrani and Collard 2002; Collard and Tehrani 2005; Jordan, 2007).

This chapter opens with a review of how cultural transmission can be understood from a broadly evolutionary perspective and then presents a case study examining material culture diversity among Khanty communities in north-west Siberia. Observed differences in male and female clothing styles raise a series of questions at the heart of recent debates about the evolution of regional diversity in material culture—for example, the degree to which craft traditions are subject to heritable continuity within social groups, or the degree to which they are borrowed and blended between communities (Collard and Tehrani 2005; Tehrani and Collard 2002; Jordan 2007; Jordan and Shennan 2003, 2005). The study combines independent information on kinship, interaction, and ways of life with network-based analytical methods to explain why patterns of cultural diversification followed their particular trajectory. The investigation concludes with a suite of further questions that lie beyond the scope of the present chapter but that indicate promising avenues for further research both within the region and beyond.

UNDERSTANDING CULTURE AS A SYSTEM OF SOCIAL INHERITANCE

At the heart of anthropology and archaeology are long-standing concerns with how traditions are passed from one generation to the next and how these result in both cultural continuity and long-term culture change. In recent years, dual inheritance or cultural transmission theory (Cavalli-Sforza and Feldman 1981; Boyd and Richerson 1985; Shennan 2002) has provided a set of coherent predictions about how social learning and the wider cultural transmission process can generate specific patterns of cul-

tural diversity. Explicit parallels are drawn between processes of cultural “descent with modification” (social learning, selection, innovation, and drift) and the evolutionary processes of biological reproduction, selection, mutation, and drift, which are argued to share broad similarities but also fundamental differences—in particular, the degree to which cultural traits can spread rapidly between members of the same generation and not just from an older to a younger generation.

With emphasis on tracking heritable continuity, the two systems of social and genetic inheritance are argued to share enough similarities to warrant the use of models and methods developed in evolutionary biology in studies of cultural transmission (Boyd et al. 1997). For example, biologists have long-standing interests in identifying the relative contributions of ancestral traits transmitted vertically within taxa, of independent convergent adaptation, and, in at least some species, of the exchange of genetic material. In the same way, anthropologists or linguists interested in macroscale patterns of cultural transmission have expressed interest in tracking the degree to which cultural practices or languages have been passed down within communities, have evolved independently, or have been borrowed and blended between them (Mace et al. 2005; Lipo et al. 2006b).

In recent decades, biologists have largely used cladistic methods to reconstruct patterns of relationship based on descent (e.g., Kitching et al. 1998). Based on well-established models of biological speciation, these methods start out with the assumption that branching processes have generated patterns of observed diversity, which are represented by means of tree diagrams. Various statistical tests can then establish the degree to which the tree model fits the “descent” signals in the data. In the last few years, however, network-based methods have begun to be used (Husan and Bryant 2006a; also see later discussion). These serve a more exploratory role: they make no a priori assumptions about patterns of descent within a data set and have the advantage of being able to both plot both treelike

patterns of descent, as well as explore more complex scenarios where intensive lateral transfer has made a significant contribution, but they do not as yet provide statistical measures of the degree of reticulation in the network.

Equipped with these models and methods, together with others, increasing numbers of empirical culture evolutionary studies are exploring patterns of similarity and difference in culture and language across different populations, generating new insights into the underlying patterns of cultural evolution, the degree to which cultural transmission is canalized by linguistic transmission, and the degree to which different domains of culture track one another with varying degrees of fidelity through time (see chapters in Lipo et al. 2006b and Mace et al. 2005 for recent overviews of the field).

The cladistic method has been at the center of a suite of recent studies that have aimed to establish the extent of heritable cultural continuity within populations, versus lateral borrowing and hybridization between social groups (Collard and Tehrani 2005; Tehrani and Collard 2002; Jordan and Shennan 2003, 2005; Lipo et al. 2006b; Mace et al. 2005). However, since cultural transmission is grounded in networks of social learning, this untangling of the relative contributions of vertical versus horizontal transmission represents only a “mapping stage” that must be integrated with other contextual insights in order to explain why cultural transmission followed different pathways in different historical settings (e.g., Tehrani and Collard 2002; Collard and Tehrani 2005; Jordan, forthcoming). Further studies are required to link analysis of “pattern” more fully with attention to empirical “process.” This demands combining microscale behavioral information (on social learning, interaction, kinship, and mobility) with reconstruction of the macroscale trajectories of cultural diversification (Lipo et al. 2006a, 302).

Given these potentials, this chapter makes two broad contributions to culture evolutionary studies. First, the case study aims to demonstrate the utility of integrating more “traditional” ethnographic and historical data into “descent

with modification” research. Second, the study employs network-based analytical methods that have, to date, seen only limited application in recent culture evolutionary research (see Jordan, forthcoming, for material culture; but see Bryant et al. 2005 for an example of use in historical linguistics) in contrast to the expanding use of cladistic methods right across the social sciences (Lipo et al. 2006b; Mace et al. 2005).

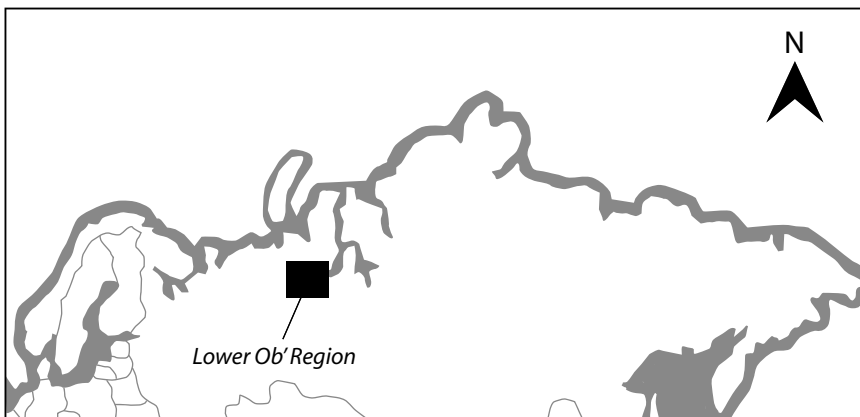
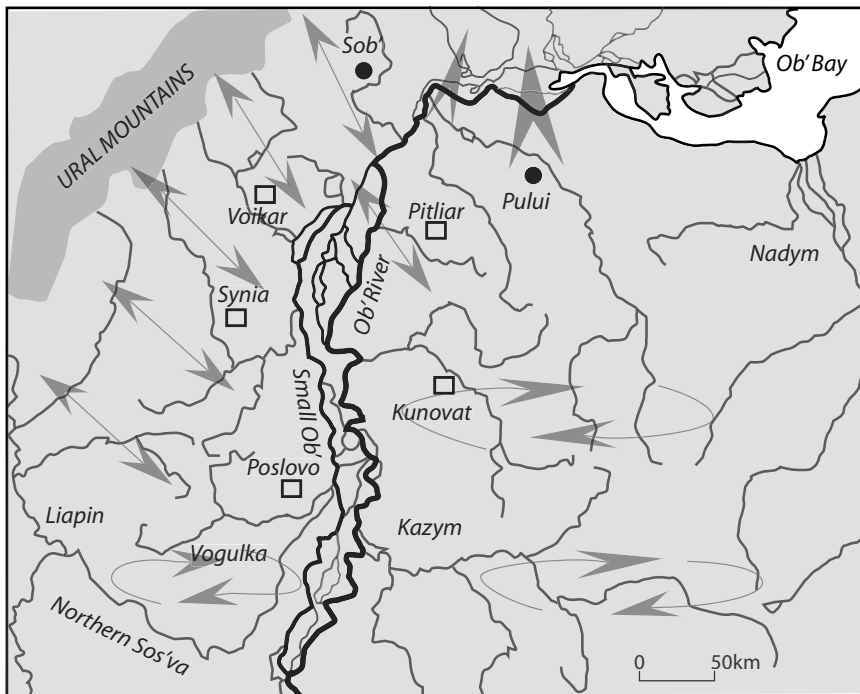
CULTURAL TRANSMISSION IN NORTHWEST SIBERIA (1600 CE–2000 CE)

The Khanty are hunting, fishing, and reindeer-herding communities who reside along the lower reaches of the Ob’ River, western Siberia (figure 5.1). This northern group of Khanty number around 7,200 individuals (1989 census, cited in Randymova 2004, 3), who maintain very high levels of “traditional” culture relative to the southern and eastern Khanty groups who live further to the south (Martynova 1998, 80, 123).

DIVERSITY IN NORTHERN KHANTY MATERIAL CULTURE

Northern Khanty produce a range of parkas, fur coats, boots, and other decorated garments as part of a rich and regionally distinctive folk tradition (figures 5.2–5.16), which has recently been documented by Siazhi (2000;¹ see table 5.1).

Male clothing consisted of the *malitsa* (hooded fur coat; figure 5.5), over which a *navershnitsa* (canvas smock; figure 5.6, showing details of one local variant) was worn. In colder weather, a *gus’* (hooded winter topcoat of fur or cloth; figure 5.7) or parka was added (figure 5.8; note major differences in the overall cut, hood details, and decoration techniques between this garment and the *gus’*; figure 5.7), especially for long journeys in heavy frost. Various kinds of fur boots, with specific seasonal and other assorted variants, were worn (figures 5.3 and 5.4). The northern Khanty also had distinctive knife-carrying belts, which were worn over *navershnitsa* and subject to decoration in different ways according to local traditions (figure 5.2).



*Forest Reindeer herding
(Stationary)*



*Forest - Tundra Reindeer Herding
(River valleys to mountain tundra)*



*Tundra Reindeer Breeding
(large scale)*

Khanty Dialects



Shuryshkarskii



Priural'skii

FIGURE 5.1 Location map of the Lower Ob' region of Western Siberia (redrawn from Perevalova 2004, 274), showing major rivers and Khanty communities mentioned in the text. Forms of reindeer herding and general directions of migrations are indicated. The different dialects of Khanty spoken by the communities (Siazi 2000) are indicated by the symbols. (Note: The communities reside and migrate along the full length of the rivers and are not concentrated at the location points of the symbols.)

TABLE 5.1. *Sample Data*

SELECTED MALE CLOTHING	KUNOVAT	POSLOVO	SYNIA	VOIKAR	PITLIAR	SOB'	PULUI
Malitsa	1	1	1	1	1	1	1
Material: skins of 3 deer not more than 4 or 5 months old	1	1	1	1	1	1	1
Cut of hood: Khanty type	1	1	0	0	0	0	1
Cut of hood: general Komi-Zyrian type	0	0	1	1	1	1	0
Length: to knee, to 10 cm below	0	0	1	1	0	0	0
Length: 10–15 cm below knee	1	1	0	0	1	0	0
Length: 15–20 cm below knee	0	0	0	0	0	1	0
Length: 20 cm below knee	0	0	0	0	0	0	1
Decorative mounting; edge of cloth along structural seams	1	1	1	1	0	1	1
Decorative mounting: ornament also on mittens, along structural seams and <i>zubchiki</i>	0	0	0	0	0	1	1
Navershmitsa	1	1	1	1	1	1	1
Material: dark one-tone cloth only	1	1	1	1	1	0	0
Material: dark one-tone cloth, plus colored cloth	0	0	0	0	0	1	1
Cut of garment: tuniclike, with skirts	1	1	1	1	1	1	1
Decorative mounting: different-colored cloth along hem, cuff	0	0	1	1	1	0	1
Decorative mounting: different-colored cloth along hem, cuff, and collar	0	0	1	1	0	0	0
Gus' (Fur)	1	1	1	1	1	1	1
Material: 4 furs of 4- or 5-month- old deer	1	1	1	1	1	1	1
Coloration: motley	1	1	1	1	1	1	1
Coloration: white	1	1	1	1	1	1	1
Coloration: spotted	1	1	1	1	1	1	1
Coloration: black	0	0	0	0	0	1	1
Coloration: gray	0	0	0	0	0	1	1
Cut of garment: general form	1	1	1	1	1	1	1
Cut of hood: general form	1	1	1	1	1	1	1
Length: 20 cm below knee	1	1	1	1	1	0	0
Length: 25–30 cm below knee	0	0	0	0	0	1	0
Length: 30–35 cm below knee, to ground	0	0	0	0	0	0	1
Decorative mounting: appliqué strips on cuffs	1	1	1	1	1	0	0
Decorative mounting: simple appliqué patterns on cuffs	1	1	1	1	1	0	0
Decorative mounting: complex appliqué patterns on cuffs	0	0	0	0	0	1	1
Decorative mounting: cloth tassels attached	0	0	0	0	0	1	1

NOTE: Adapted from Siazii (2000); for full data set, see <http://www.cecd.ucl.ac.uk/home/>.



FIGURE 5.2 Details of male belt showing knife and ornamentation details.

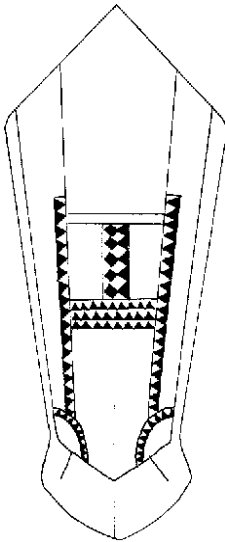


FIGURE 5.3 Details of male boot uppers (*evtom vai*), showing decorative cloth stripes along the structural seams.

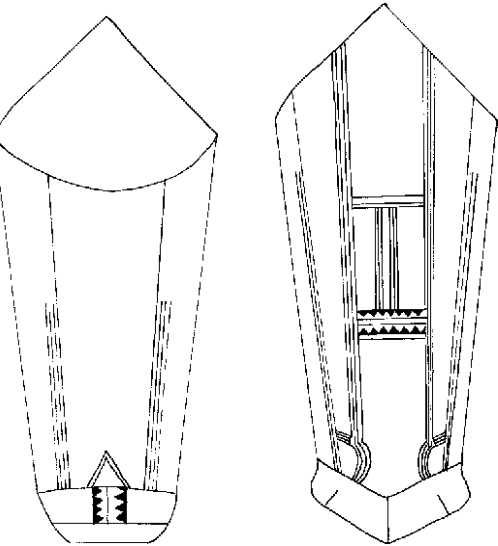
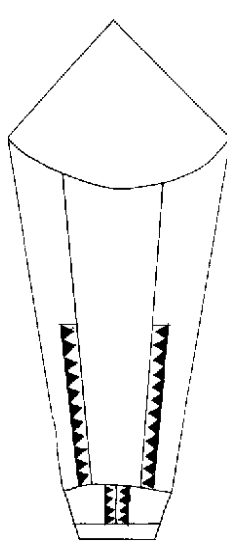


FIGURE 5.4 Details of male boot uppers (*khanshan vai*), showing the insertion of ornamental panels along the structural seams, a design feature copied from Nenets traditions (Siazi 2000, 176).



FIGURE 5.5 Male clothing (*malitsa*—fur smock—general view).

Women's clothing sets included fur boots, fur hats, dresses, headscarves, a decorated cloth gown known in Khanty as a *sakh* (figures 5.15, 5.16). The most distinctive garment was the highly decorated fur coat (termed here in Russian *shuba*), which was made according to a shared general design across region, with a "multitude" of local variants (Siazi 2000, 32). Compare figures 5.9–5.14, noting differences in the degree, format, and location of decoration on different parts of the coat.

At a general level, Siazi (2000, 15; see also later discussion here) links the design of the garments to the practical demands of the region's mobile hunting, fishing, and reindeer-herding economy, which also provided the furs. Siazi also suggests that the clothing performed

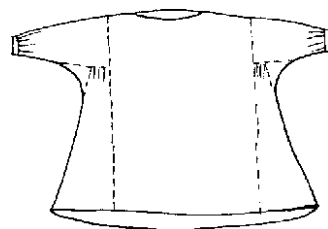
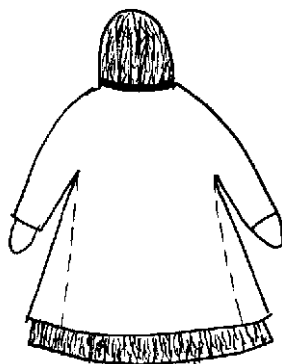


FIGURE 5.6 Male clothing (*navershniitsa*—front, rear, and general views to illustrate how the garment is worn over the *malitsa*).

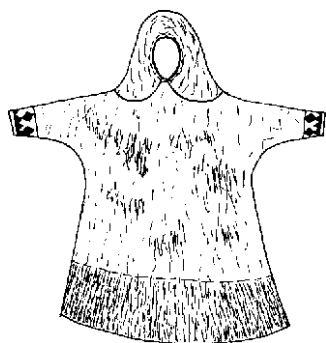


FIGURE 5.7 Male clothing (*gus'*—fur overcoat worn in very heavy frosts).



FIGURE 5.8 Male clothing (*parka*—worn in very heavy frosts).



FIGURE 5.9 Female clothing (*shuba*—fur coat—general view of garment, rear) made by speakers of the Shuryshkarskii dialect (see figure 5.1).



FIGURE 5.10 Female clothing (*shuba*—general view of garment, front) made by speakers of the Shuryshkarskii dialect (see figure 5.1).



FIGURE 5.11 Female clothing (*shuba*) from Pitliar Khanty, rear.

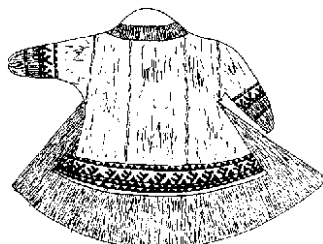


FIGURE 5.12 Female clothing (*shuba*) from Pitliar Khanty, front.



FIGURE 5.13 Female clothing (*shuba*—general view of garment, rear) made by speakers of the Priural'skii dialect (see figure 5.1).



FIGURE 5.14 Female clothing (*shuba*—general view of garment, front) made by speakers of the Priural'kskii dialect (see figure 5.1).



FIGURE 5.15 Female clothing (*sakh*—cloth gown—general view of garment, rear) made by speakers of the Shuryshkarskii dialect (see figure 5.1).



FIGURE 5.16 Female clothing (*sakh*—general view of garment, front) made by speakers of the Priural'kskii dialect (see Figure 5.1).

a “differentiating” function, marking individual wearers according to sex and age, but also expressing territorial, ethnic, and religious identities (17). For example, the “national” dress of the Lower Ob' Khanty was unique in relation to both other Khanty and neighboring nationalities (e.g., the Nenets, Mansi, Komi). Upon seeing a stranger in traditional costume, a Khanty could easily tell by the cut, sewing, and ornamentation of garments exactly where the person had originated from, with those from other regions described in Khanty as *na muv khoiat* (Russian, *chuzhikh zemel' chelovek*—literally, “person from others’ lands”; 18).

Siazi describes overall similarity in clothing styles *within* each of the seven communities that form the focus of her study—the Kunovat, Poslovo, Synia, Voikar, Pitliar, Sob', and Pului Khanty (figure 5.1)—but she also goes on to explore considerable intercommunity variation among them. This variability was documented by assembling information about each single category of garment from across the region (e.g., the *shuba* fur coat; 18, note 1). Each garment category was then described in relation to a defining set of basic “traits” (e.g., the materials, color, cut, and decoration style employed in the making of a *shuba*). Next, the specific variations in these individual traits across the communities was recorded. For example, all groups made the *shuba* with a fur collar, but only the Kunovat, Poslovo, and Synia Khanty used fox and sable fur for that collar, while deer and polar fox pelts

were used to make the collar among the Voikar, Pitliar, Sob', and Pului communities, but not by the other groups. This exercise generated a comprehensive presence–absence list of clothing and footwear variation across the seven Khanty communities for a range of different garment and boot types (for wider discussion of how this general classification method relates to culture evolutionary studies, see Holden and Shennan 2005, 14; Jordan, forthcoming).

Understanding the origins of these patterns of similarity and difference in these clothing assemblages revisits long-standing debates about the operation of cultural “descent with modification”—in particular, the degree to which craft traditions are inherited vertically within communities or appear through more complex processes of blending and borrowing traits between social groups.

What specific factors might have impacted on cultural diversification? In traditional Khanty society, there was a strong division of tasks according to gender lines. While Khanty men worked with reindeer and made sledges and skis, the processing of animal skins and manufacture of garments had strong links with female domains of activity. In addition, all categories of clothing examined in the present study were sewn by women from separate household units; only in very rare situations—for example, in the highly complex job of stitching ornamentation for boots—was the assistance of a “master” seamstress called for (Randymova 2004, 89).

Ethnographic insights also point clearly to the skills and practices associated with the making of clothing and footwear being passed down a strictly female line of transmission, with most learning taking place by direct biological offspring (Siazi 2000, 16)—a familiar theme in the wider literature on apprenticeship in small-scale societies (Shennan and Steele 1999).

Consideration of a wide range of historical and archaeological data leads Siazi to conclude that there has been long-standing conservatism in the *basic* manufacture, ornamentation, and cut (in Russian, *pokroi*), which has been stable for several generations, if not centuries. Social sanction appears to have played a role in ensuring continuity in design: “a woman did not have the *right* to change the generally accepted (Rus, ‘obshchepriniaty’) cut which was passed on from generation to generation” (Siazi 2000, 18, emphasis added).

All these insights suggest strong heritable continuity in the basic garment designs, which were passed predominantly from mothers to daughters. How might this have impacted on larger-scale patterns of clothing diversity among the communities? If generations of Khanty seamstresses stayed within a single community, perhaps fostering a closer sense of group identity and encouraging local convergence in clothing styles and exclusion of external influences, then the likely long-term outcome would have been the formation of distinct stylistic “lineages” of clothing, each exclusive to a single community. Such processes would be reinforced, for example, if the clothing had come to express “emblemic” style, signaling community identity (Wiessner 1983) to other groups. Such differences may also have persisted despite frequent social interactions between groups (Barth 1969; Hodder 1982).

Other kinship patterns may have overturned this tendency. First, even if the skills were initially passed between biological mothers and their daughters, the practices would gradually have been imported into other communities as part of population movements between groups. For example, households may shift their residence for

economic or political reasons, or as females moved after marriage, although social sanction in the new community might force them to adopt local practices. Moore (2001, 43) has stressed intercommunity marriage as a powerful mechanism for enabling dispersal of cultural traits over vast geographic distances and across cultural and linguistic frontiers. If recent centuries along the Lower Ob’ were also characterized by intercommunity marriage and migration, we might predict that similarities in material culture would be greatest among groups who had interacted and exchanged partners most frequently (Wobst 1977). This frequency of interaction may have been related rather directly to geographic proximity, although the requirements of the mobile subsistence round may have brought together distant communities for intensive but short-term periods of cohabitation (e.g., during annual fish runs).

Similar outcomes might be expected if clothing style was employed to signal the *individual* qualities of the maker, expressing skill, judgment, and individual physical attractiveness rather than a single sense of community identity. This more “assertive” (Wiessner 1983) and individualistic expression of style through the use of conspicuous items of clothing might provide motivation for the expression of creativity within an otherwise conservative tradition. Women may have been encouraged to innovate and borrow freely from other groups and individuals that they came in contact with through trade or seasonal migrations. It is worth noting here that in the context of this creativity, the predominantly vertical transmission of craft *skills* may not have impeded the ready horizontal transmission of specific clothing *traits*. For example, new decorative combinations of cloth and fur could easily have been invented or adopted from other individuals by any Khanty seamstress, despite the fact that the basic craft skills had been acquired during an earlier period of mother–daughter apprenticeship. Through time, these processes would gradually erode sharp stylistic differences between the female clothing traditions of the various groups, but

they would not necessarily require intermarriage or household migration between groups, just frequent opportunities for general interaction and information exchange, perhaps linked to the patterns of the seasonal round. However, how this individualistic expression of female style might relate to the design of male clothes also made by seamstresses for their menfolk is less certain. It may follow that without this motivation to innovate, blend, and borrow, the manufacture of male clothing styles may have remained more conservative and been more closely linked to the mother–daughter learning roles and through time to deeper community history.

In summary, exploration of the ethnographic record identifies a number of reasons for suspecting that cultural diversification in the region may have followed quite different trajectories, generating either crisp stylistic differences or a more general “smudging” of traditions between the communities. However, the degree to which one scenario predominates over others will have been determined, to a major extent, by the specific details of kinship, mobility, and interaction practices. These factors formed the crucial behavioral and historical contexts in which individual action and personal intent generated longer-term culture change.

NORTHWEST SIBERIA: THE HISTORICAL CONTEXT (1650 CE–2000 CE)

The northern Khanty live along the lower reaches of the River Ob', which drains the West Siberian Plain. The region's ecology is strongly continental, comprising boreal forest (taiga) in the south, expanses of arctic tundra in the north, and a chain of alpine tundra running along the Ural summits (figure 5.1). The Lower Ob' lies at the intersection of many different cultural and linguistic influences. Historical records indicate that the river banks and major tributaries were populated by Khanty (Ostiaks), with Mansi (Voguls) to the west, Nenets (Samoyeds) to the north, and Komi to the northwest. Khanty and Mansi spoke various Ob-Ugrian dialects, Nenets

was a Samoyedic language, and the Komi spoke Finno-Ugric dialects, all of which fall into the broader Uralic group of languages. In colonial times, isolated Russian populations settled along trade and administrative outposts along the main rivers.

The integration of diverse subsistence practices has given form and content to settlement, mobility, and interaction patterns across the region:

- The Lower Ob' includes some of the richest fishing grounds in Eurasia due to unique set of ecological factors (Sirelius 1906; Federova 2000). During earlier prehistory, local communities subsisted primarily through various forms of local lake and river fishing, practiced year-round, and the interception of major seasonal runs along the main channels during the summers.
- Hunting for wild reindeer and elk (moose) provided meat and other resources, while winter hunting of sable, mink, squirrel, fox, and other fur bearers provided valuable pelts for trade (Golovnev 1993; Federova 2000; Perevalova 2004).
- Reindeer taming and domestication has a long history in the area. From the Iron Age, small herds were initially kept for transport and as hunting decoys (Golovnev 1993; Ingold 1980, for a wider discussion). The last four hundred years witnessed a wholesale “reindeer revolution” as some hunters switched to the full-scale management of large herds that provided full subsistence (Golovnev and Oshrenko 1999, 16). These herders followed their domestic reindeer on long-distance seasonal migrations, with winters spent at the sheltered tree line and summers out on the windswept tundra, where there were fewer insects. Smaller-scale herding also spread into the forest zone and provided transport for hunters to access new areas for trapping. Here, localized migrations between pastures were integrated into the seasonal hunting and fishing round (Golovnev 1993; see figure 5.1).

The region was colonized by Russia in the later sixteenth century as part of the expanding international fur trade (Forsyth 1992). Small numbers of Cossacks built fortified towns along the Ob' and imposed a *yasak* fur tax on local populations. Members of the indigenous communities were registered into administrative units for the collection of this tax, generating colonial records that provide detailed insights into demography, kinship, and interaction. Despite the imposition of tight fiscal control over the fur trade (Anderson 2004, 254), general contact between Russians and locals was sporadic (Martynova 1998, 102–103) but later included missionary activity (Glavatskaia 2005). With state interests lying primarily in securing a steady supply of fur, native land rights were enshrined in law (Shimkin 1990), creating de facto apartheid between small colonial populations concentrated on the main and lower tributary rivers, and the native hunters, fishers, and herders of more outlying regions (Jordan 2001, 2003).

The indigenous groups in the Lower Ob' region were registered into the Obdorsk and Kunovat *volosti* (the smallest administrative units of czarist Russia) (see map 2 in Perevalova 2004, 170). Census materials suggest initial increases in the Khanty population, followed by limited falls during the nineteenth century (table 5.2). By the last Soviet census (1989), these Khanty fell into Shurysharskii District (5,000 Khanty) and Priural'skii District (2,500 Khanty) of Yamalo-Nenets Autonomous Region (Siazi 2000, 4). On balance, Khanty populations did not witness the kinds of catastrophic demographic collapse that

affected regions like California and the Pacific Northwest Coast during the same colonial period (Cook 1978; Boyd 1990), which must have had significant implications for the inheritance of cultural traditions (see Shennan 2000).

While the Kunovat and Obdorsk *volosti* were territorial units “invented” by colonial administrators, they encompassed a series of more “localized” groups with their own senses of identity (Perevalova 2004, 211). These included the seven Khanty communities that form the focus of the present study (Siazi 2000; table 5.2). Most occupied a single river, with group identity grounded in intensive local patterns of subsistence-based interaction; in some cases, groups also worshipped at a central sacred site (Perevalova 2004, 211–213; see also Martynova 1998, 124). Five of the southern groups speak the same Shuryshkarskii dialect of Khanty, while the two northern communities speak the Priural'skii dialect (table 5.3).

Historical archives also provide fine-grained insights into marriage patterns and more general population movements (Perevalova 2004, 170; Martynova 1998, 80). From approximately 1650 CE to 1800 CE, there is evidence of intensive inter- and intraregional migrations, which are reflected in a rapid turnover of local family names and are possibly linked to the imposition of the new fur tax regimes, as well as the associated commercialization of hunting that may have pushed families to seek out new territories in order to pay their tax quotas (Martynova 1998, 87). This era of mass migration was followed by a more stable period characterized by greater

TABLE 5.2. *Khanty Demography in the Lower Ob', 1650–1900*

YEAR CE	OBDORSK VOLOST'	% CHANGE	KUNOVAT VOLOST'	% CHANGE
1650	744		552	
1700	1,560	110% growth	1,240	125% growth
1800	2,032	30% growth	1,360	10% growth
1815	3,341	64% growth	1,743	28% growth
1850	2,973	12% fall	1,698	3% fall
1900	2,441	17% fall	1,684	1% fall

SOURCE: Perevalova (2004, 178). These figures must be read with some caution as the sudden increase in 1700 probably reflects Russian state attempts to register more fur tax payers, movement of Khanty into the area from the south, as well as local community births and deaths (Perevalova 2004, 214–215).

TABLE 5.3. *Lower Ob' Khanty: Linguistic Affinity, Subsistence, and Mobility Practices*

COMMUNITY	NAME IN KHANDY ^a	DIALECT	ECOLOGY	TRADITIONAL ECONOMY AND MOBILITY PATTERNS
Kunovat	<i>Kunovat ekh</i> (2000:49) (Kunovat people)	Shuryshkarskii	Taiga	Hunting, fishing, domestic reindeer herding (much reduced following Soviet-era destruction of reindeer herds; now only 400 reindeer in two brigades; very localized migrations)
Poslovo	<i>Poslan ekh</i> (people of the channel)	Shuryshkarskii	Taiga	Mainly hunting, fishing, no domestic reindeer herding (this ended with 1940s enforced settlement of the community)
Synia	<i>Shchania ekh</i> (Synia people)	Shuryshkarskii	Taiga	Hunting, fishing, domestic reindeer herding (five brigades, each with around 2,000 reindeer; summer spent in the Urals, winter in the Synia basin)
Voikar	<i>Ekhan ov ekh</i> (people of the estuary)	Shuryshkarskii	Taiga, forest tundra	Hunting (winter), fishing, domestic reindeer herding (three brigades with 1,000–1,500 reindeer; summers spent in the Urals and beyond)
Pitliar	———	Shuryshkarskii (but priural'skii also spoken since 1970s)	Taiga, forest tundra	Hunting, fishing, domestic reindeer herding (winter near the Ob'; summer in the Polar Urals; several brigades with 2,500–5,000 reindeer)
Sob'	<i>Sup poslen ekh</i> (Sob' people of the channel)	Priural'skii (Obdorsk)	Forest tundra	Hunting, fishing, domestic reindeer herding (three brigades, around 2,500 reindeer in one, size of other herds not stated; winters on Sob', Sobtyiugan, summers in Urals and beyond)
Pului	<i>Pul ekh</i> (Pului people)	Priural'skii (Obdorsk)	Forest tundra, tundra	Hunting, fishing, domestic reindeer herding conducted at immense scale (ten brigades, some of mixed ethnicity; winters in and around the Ob' and on the Pului, summers in the Polar Urals and along the shores of the Baidaratskii Bay on the Kara Sea)

^aFrom Siazii 2000.

stability in local family names, although traces of a “significant” rather than “sizeable” flow in populations continues (Perevalova 2004, 215). Memories of general social mobility survive in the folklore, with most groups recounting origins outside their present places of residence (Martynova 1998, 87).

Many of these new forms of contact appear to be linked to transformations in the colonial

economy. The nineteenth-century boom in commercial fishing brought in Khanty from diverse regions, some of whom settled as sedentary fishing groups along the main Ob' banks; others migrated in seasonally to the main Ob' River from the upper reaches of the tributary rivers, and they often spent several weeks camping out on the river sands with members of distant communities during the main summer fishing

season (Martynova 1998; Ahlqvist 1885, 211; Perevalova 2004, 258; Shimkin 1990; Kulemzin and Lukina 1992; Federova 2000). Perevalova (2004, 257) stresses the vast scale and intensity of these seasonal intercommunity contacts and suggests that commercial fishing, in particular, created the conditions for the “consolidation of northern Khanty society.” By the nineteenth century, almost the whole population of the Lower Ob’ was engaged in commercial fishing activities (Perevalova 2004, 257), with those living along the riverbanks particularly strongly affected (table 5.3).

Different regional patterns of reindeer husbandry also emerged (Martynova 1995), increasing intercommunity contacts across the Lower Ob’, as well as with regions and other communities lying beyond (see figure 5.1; Perevalova 2004, 270), especially among those groups practicing large-scale husbandry, which demanded long-range migrations to the north and north-east (figure 5.1 and table 5.2).

By the early twentieth century, the northern Khanty were integrated into a regional economic system, with commercial links stretching outward to the demands of world fur and fish markets. A lively internal trade within and between the rivers also created exchange contacts between hunting, fishing, or herding specialists, while the northern herders who spent long periods out on the treeless tundra also swapped their reindeer hides for sleds, canoes, and birch bark materials made by hunters and fishers in the forest zone. In conclusion, recent centuries have witnessed a steady increase in population levels combined with increasing degrees of social connectivity right across the Lower Ob’ and beyond (figure 5.1 and table 5.3). How might this historical context have affected cultural transmission?

QUANTITATIVE ANALYSIS OF MATERIAL CULTURE VARIABILITY

The distribution of cultural traits across the seven communities was subjected to quantitative analysis within a broadly evolutionary framework in

order to answer three main questions about cultural diversification:

- What are the *general* patterns of cultural transmission (i.e., branching or blending) affecting all traits, and how do they relate to the known interaction patterns, kinship practices, and demographic processes already noted here?
- Have male and female clothing traits, as well as individual classes of garment (e.g., the female *sakh* and *shuba*), been affected by similar processes of transmission, or does each have a different descent history?
- What is the relationship among cultural diversity, relative geographic location, and the dialect frontier that runs through the study area (table 5.2 and figure 5.1)?

Considering the ethnohistoric insights into learning, interaction, and exchange presented in this chapter, we have no reasonable way of knowing whether cultural traditions have been transmitted vertically within the communities, which would generate branching patterns of descent, or whether a more complex pattern of transmission, characterized by frequent horizontal borrowing and hybridization, has predominated. These factors make it difficult to establish, *a priori*, the appropriate general model of cultural evolution in the region.

As Bryant and Moulton (2004) make clear, there is no model-free way of analyzing data sets; and while general treelike models of speciation are well established in evolutionary biology, caution is advised when applying the models to cultural or even biological data sets whose general patterns of evolution are poorly understood. Hulan and Bryant (2006a) explain that “in tree-based phylogenetic analysis the goal is to find the phylogenetic tree that best explains the patterns in the data . . . [but] . . . the . . . method will attempt to fit a tree, even if there is still a huge gap between the data and the best tree that the method can find” (258).

Given the uncertainties in the present case-study, a more heuristic exploration of the data is

advisable at this stage. In recent years, network-based methods have been developed as a tool for exploring general patterns of evolution where complex scenarios of descent with modification are poorly investigated with tree-based analysis:

The familiar evolutionary model assumes a tree, a model that has greatly facilitated the discussion and testing of hypotheses. However, it is well known that more complex evolutionary scenarios are poorly described by such models. Even when evolution proceeds in a tree-like manner, analysis of the data may not be best served by forcing the data onto a tree or assuming a tree-like model. Rather, visualization and exploration of the data to discover and evaluate its properties can be an essential first step.

Husan and Bryant (2006a, 254)

The NeighborNet technique (Bryant and Moulton 2004) is a network-based method that can “represent data without assuming that the data is tree-like” (Bryant et al. 2005, 80). The method is outlined in detail by Bryant and Moulton (2004; see Bryant et al. 2005 for a recent application to analysis of linguistic descent history) and is based on the mathematical concept of a “split” (Husan and Bryant 2006b, 7–9).

The first step of analysis is the generation of a distance matrix from the assemblage of traits. These distances are then used to generate a series of splits in the data, using an agglomerative clustering algorithm, which progressively combines clusters in ways that overlap, into larger and larger overlapping clusters. Weights are then calculated for these splits and are represented in the form of a network diagram—or data “snapshot”—known as a splits graph (see Bryant et al. 2005, 68–69, 74–79). These “split networks are very useful for exploring and visualizing the different signals in a dataset [*sic*]” (Husan and Bryant 2006a, 263) and can be regarded as a “tool for vizualisation” (Huson and Bryant 2006a, 254).

If phylogenesis has been the dominant process of descent, then the splits graph will closely resemble a tree diagram, as descent with modification will have proceeded in a strict

branching manner, making the splits compatible. However, if horizontal borrowing and hybridization have been widespread, then the diagram will be much more complex, with conflicting signals represented as boxlike sections in the graph—the larger the box, the greater the conflict in the data, and the greater the role of horizontal transfer.

In summary, the NeighborNet plots contain two kinds of information: “the splits, which represent the groupings in the data; and the branch lengths, which indicate the degree of separation for each split” (Bryant et al. 2005, 77). As a result, the splits graphs can be interpreted in terms of groupings in the data, with longer branch lengths indicating a greater degree of difference (see Bryant et al. 2005). In the current study, NeighborNet (Bryant and Moulton 2004) incorporated into SplitsTree4 V4.4 (Husan and Bryant 2004, 2006a, 2006b) was employed, with the distance measure set as “UncorrectedP.”

RESULTS OF NEIGHBORNET ANALYSES

The examination of material culture variability proceeded from analysis of the entire collection of traits (male and female clothes and all male and female footwear as a single “package”; see table 5.1 for a sample of the data set) through to the “breaking open” of this cultural package to facilitate analysis of smaller and smaller subsets of traits, including male and female clothing and footwear traits, and finally specific kinds of female garment, the *sakh* and *shuba*.

Five NeighborNet plots are presented in figures 5.17–5.21 and indicate several general features of cultural transmission in the region. First, descent histories have been complex, with numerous boxes in all plots indicating significant cultural hybridization, rather than crisply branching patterns of descent. Second, the Sob’ and Pului Khanty are drawn out from the other groups in all plots (particularly clearly in figures 5.17 and 5.18, slightly less so in figures 5.19 and 5.20, and to some extent in figure 5.21), which is interesting because these distinctions in material culture map onto the dialect frontier

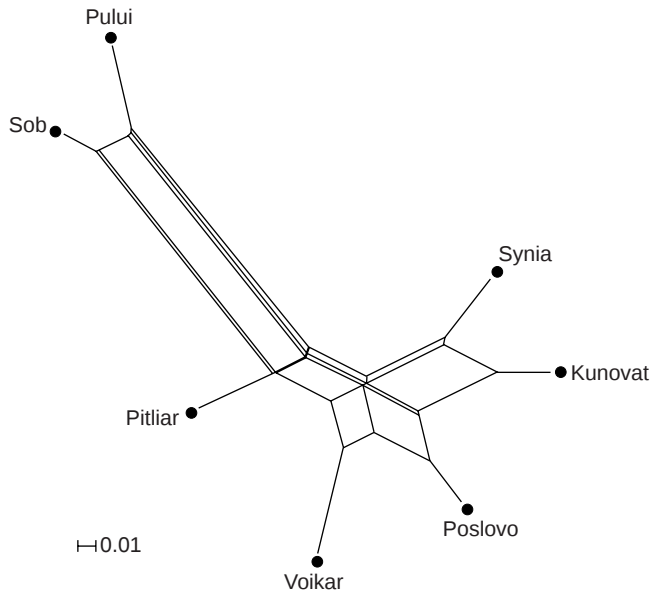


FIGURE 5.17 NeighborNet plot: All Traits (male and female clothing and footwear).

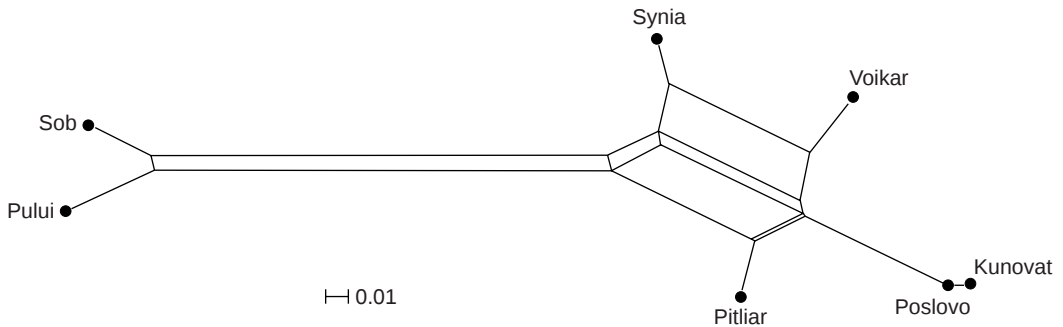


FIGURE 5.18 NeighborNet plot: All Male Traits (clothing and footwear).

(table 5.2) that runs across the Ob' (figure 5.1). In contrast, clothing variation within the Shuryshkarskii dialect area is more varied and will be discussed later. This dialect frontier also appears to be one acknowledged by the local communities themselves. For example, informants from the southern communities perceive "sharp" differences in the dress of the northern groups, and they describe a dialect characterized by extensive borrowings from Nenets language, which makes it hard for them to understand (Perevalova 2004, 212).

Census data generate deeper insights into how this cultural frontier may have been maintained. At the end of the eighteenth century, the Sob' and Pului fell within the Obdorsk *volost'*,

with the Voikar Khanty just inside this border. Five hundred Khanty marriages took place in the territory during this period (Perevalova 2004, 216), with 412 involving partners from entirely *within* the area, of which 142 included marriages between Khanty and Nenets (though no mixed marriages are recorded for the Voikar). Only 57 marriages involved Khanty moving in from the Kunovat' *volost'* to the south (which included the Kunovat', Poslovo, and Synia Khanty), and only 25 marriages brought in partners from areas much farther south. In contrast, marriages recorded in the Kunovat' *volost'* totaled 310, of which 156 involved partners only from within this area, none of whom were listed as being Nenets. Around 70 marriages involved

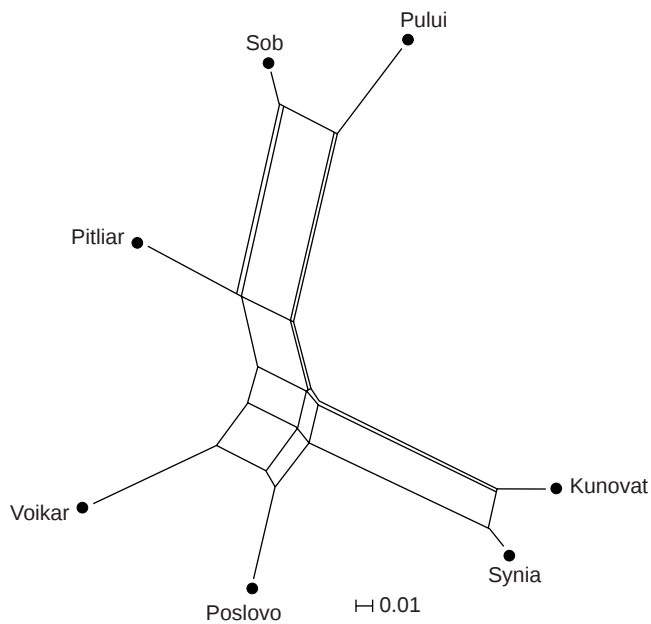


FIGURE 5.19 NeighborNet plot: All Female Traits (clothing and footwear).

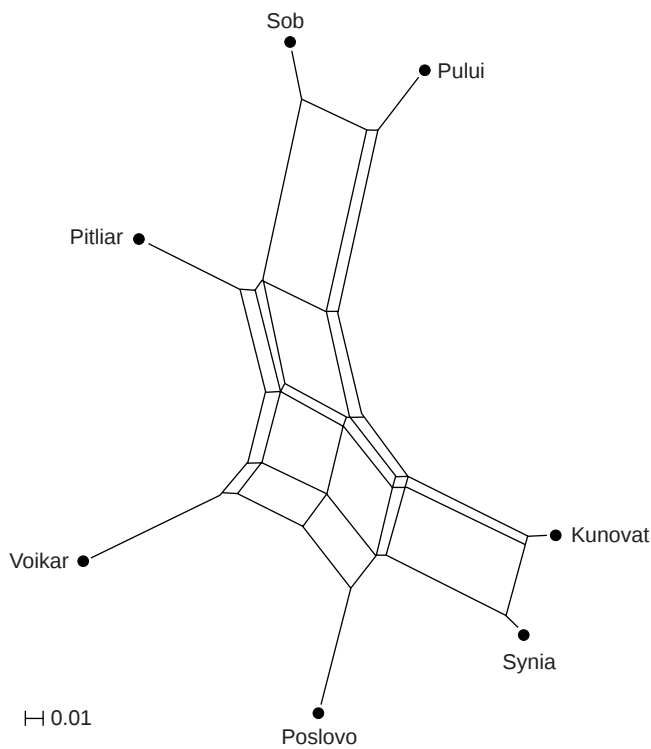


FIGURE 5.20 NeighborNet plot: Female *Shuba*.

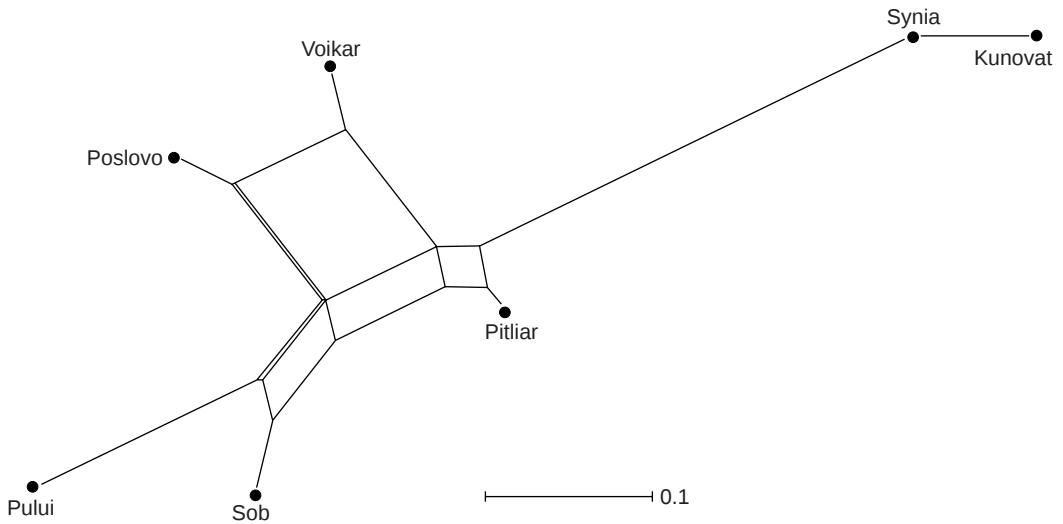


FIGURE 5.21 NeighborNet plot: Female *Sakh*.

partners moving in from the Obdorsk district to the north, but a further 88 marriages resulted in partners moving in from the Sos'va and Liapin rivers and from other areas to the south (see figure 5.1).

While the general trend is one of regional-scale intermarriage similar to the patterns noted in North America by Moore (2001), the statistics suggest different *general* orientations in the movement of partners. On the basis of detailed analysis of the census data and other archival and ethnographic materials, Perevalova (2004, 216) argues for the presence of an enduring cultural frontier characterized by divergent economic orientations, the first binding the more northerly Khanty (Sob' and Pului) into the nomadic reindeer breeding world of the tundra Nenets, and the second linking the more southerly groups (Poslovo, Synia, Pitliar, and Kunovat) with other Khanty and Mansi hunter-fisher groups living in the forest zone.

In addition to the dialect frontier, what are the more specific patterns of clothing resemblance and difference among the groups? The "All Traits" plot (figure 5.17) indicates that clothing and footwear styles among the five groups who speak the Shuryshkarskii dialect are broadly divergent from one another, although the boxes at the center of the diagram indicate that a significant degree of cultural hybridization has

proceeded between these groups. This data set includes a diverse range of male and female traits; and while the importance of the dialect frontier is readily apparent in the plot, it is difficult to interpret this "general" overview in relation to either the details of the garments or local geography, for there appears to be no straightforward association between clothing design and relative location of the communities around the region.

Figure 5.18 plots "All Male" traits and suggests a range of clear cultural distinctions in addition to those marking major differences in clothing at the dialect frontier. For example, the Synia and Voikar are pulled out to the top, and Siazhi (2000, 76) notes how these groups follow parallel migration routes up into the Urals where they frequently meet and interact. Most items of male clothing and footwear among these two groups are virtually "indistinguishable," and intercommunity marriages are also common, with Synia women marrying into Voikar households retaining their traditions for making male clothing (Siazhi 2000, 76). However, in winter the Voikar tend to wear only a fur *gus'* (figure 5.7), while the Synia, Pului, and Sob' Khanty all wear parkas (figure 5.8), which appears to be the reason that the Synia fall closer to these groups in the plot.

There is little overall difference in male footwear among the groups. Variation in clothing

styles is more marked and must be making a greater contribution to patterns pulled out by the plot. However, the variation tends to relate to more general design features like the presence or absence of extra colored cloth in the *malitsa*, the use of black or gray fur, and some extra decorative features in the *gus'* of the northern groups. The overall length of garments is generally lower among more northerly groups (see, e.g., the *malitsa* and cloth and fur *gus'*), who practice herding out on the tundra. In contrast, the Kunovat and Poslovo are much less reliant on reindeer herding (table 5.3) and tend to wear shorter garments. These have a simpler cut (e.g., the *navershnitsa* (figure 5.6), which has no additional colored cloth or decoration) and less decoration (simpler on the fur *gus'* and absent on the cloth *gus'*). Their belts are also simpler with no attached knife sheaths, and the local *evtom vai* boots are very weakly decorated (figure 5.3). Siazı (2000) notes how both the Kunovat and Poslovo Khanty suffer from shortages of quality reindeer fur due to smaller-scale herding practiced in these areas. Overall, the plot for male traits does appear to represent relative geographic location, with northern groups to the left and southern groups to the right. Intervening groups oppose each other along opposite sides as they do along the Ob', and the relative positions of the Voikar and Synia probably relate to the presence of the parkas among the Synia as noted previously.

The plot for All Female Traits (figure 5.19) is considerably different to the plot for All Male Traits. First, there appears to have been much more borrowing in female clothing traits among the groups. Second, the distribution of the groups around the plot is quite different as well. While the Sob' and Pului groups are pulled out, reflecting the dialect frontier, the Kunovat and Synia also appear to be forming a distinct cluster despite the fact that they face each other across opposite banks of the Ob' (figure 5.1). Partly this can be accounted for by the existence of intense trade links between the two groups, with both reindeer furs and finished garments traded for boats, sledges, and other "forest"

items. Exchanges appear to have been conducted via members of both communities who met on the main river while summer fishing; similar trade in fish for fur and finished garments linked the Poslovo to the Synia (Siazı 2000, 60). Common migrations and pasturing was also practiced among the Sob' and Pitliar Khanty, which may have generated further exchanges and the closer grouping of the Pitliar with the most northerly groups (table 5.2). However, due to the large number of features recorded, it is difficult to identify which specific traits are generating the overall patterns in this plot. Further analysis was conducted on the individual *shuba* and *sakh* garments.

The plot for the *shuba* (female fur coat; figure 5.20) resembles quite closely the plot of All Female Traits discussed earlier. These are indications of quite significant "hybridization" between the groups, and the presence of the dialect frontier is much less clear. However, inspection of the data suggested that there were distinct geographic variations in the more basic design features. For example, longer coats are worn further to the north, a feature also noted in male assemblages. There are sharp differences in the furs used for the *shuba* collars, and this may reflect the local availability of pelts—squirrel, fox, and sable are generally forest species and are used by groups in the south (Kunovat, Poslovo, Synia), while the use of species like polar fox are employed in the more northerly traditions (Voikar, Pitliar, Sob', and Pului). In contrast, the distribution of other design and ornamentation features is much harder to interpret, with different traits distributed almost chaotically among groups almost irrespective of their relative location.

These patterns may be indicating, first, the existence of distinct community traditions relating to garment cut and basic design (a suggestion made by Siazı [2000], 18), which are perhaps passed on vertically within the community; but, second, a more confused set of distributions affecting ornamentation style, potentially an outcome of individual creativity and choice on the part of the maker, and leading to faster

moving traditions of borrowing and blending. This potential for different aspects of the garment having different transmission histories was tested further by plotting only the first forty-one of the *shuba* traits, which record more general garment features. However, the plot (not shown) also revealed a high degree of blending, suggesting that *all* aspects of this garment have been subject to intensive borrowing and recombination across the region.

Finally, the *Sakh* (female cloth gown; figure 5.21) plot is quite different again and reveals much less conflict in the data set, suggesting a stronger branching signal. In this plot, the dialect frontier is important, though less distinct than the major differences that appear to characterize the Synia and Kunovat groups, on the one hand, and the Posovo and Voikar groups, on the other. As noted, these two groupings appear to reflect intense exchange contacts passing fur, fish, and forest products among the communities, the Kunovat and Synia trading across the Ob', and the Voikar and Poslovo from north to south. While variation in the *shuba* appears to reflect the wider set of female traits, the *sakh* has a different descent history, which also has little in common with variability in male clothing, other than general differences across the dialect frontier.

In summary, these plots suggest that hybridization has been a persistent feature of macroscale cultural evolution in the region. At the same time, there are significant differences in material culture and language running across the region and these appear to have been an outcome of long-term trends in intermarriage as well as more general cultural and economic orientations. Patterns of material culture variability within the southern dialect group are less consistent, with male and female clothing, and also different *items* of female clothing, all characterized by different descent histories. In particular, male garments and the female *sakh* appear to show traces of a stronger signal for phylogenetic history, while the full assemblage of female traits and the *shuba* garment appear to have been more strongly affected by intercommunity borrowing.

DISCUSSION AND OUTLOOK: ACCOUNTING FOR DIVERSITY IN NORTHERN KHANTY MATERIAL CULTURE

These results enable a return to the three questions raised earlier. General patterns of regional transmission are certainly complex, but the evidence indicates clearly that both branching and blending process have impacted on longer-term patterns of macroscale evolution, albeit in different ways and for different aspects of male and female clothing assemblages. In particular, cultural hybridization appears to have been a major factor, and it proceeded within the historical context of gradually expanding population levels and the emergence of lively long-range intercommunity contacts associated with the rise of reindeer husbandry and commercial fishing within a wider colonial context. Working against the more general trend toward cultural convergence was the different alignment of long-term marriage contacts along northern and southern axes, which appears to have generated a significant and enduring cultural and linguistic frontier running from east to west across the region. In summary, these results suggest that regional cultural diversity in the Lower Ob' reflects broader patterns of interaction and exchange, but in a less direct way than predicted by the simple "ethnogenesis" hypothesis (Moore 2001), where mere proximity ensures cultural similarity.

We can also revisit the anecdotal ethnographic evidence outlined earlier in this chapter that describes the tendency for vertical transmission of craft skills between mothers and daughters, but that also raises the potential for distinction between transmission of *skills* and *traits*, which might have different descent histories. Broader kinship and exchange patterns, and the use of clothing for either "emblemic" (group) or "assertive" (individual) style (Wiessner 1983), were argued to create the potential for strong vertical descent and the maintenance of crisp stylistic frontiers (Hodder 1982), a general stylistic convergence amongst those in most frequent contact (Wobst 1977), or

a set of more generalized distributions with interlocking scales of more muted stylistic difference (Welsch and Terrell 1998).

The analyses suggest that male and female clothing traits appear to have been characterized by different descent histories. There are grounds to suspect that the female *shuba* may represent an iconic statement of personal identity, with frequent recombinations of novel traits expressing the individual creativity of the maker and encouraging the borrowing of styles within a wider context of frequent intercommunity marriage that would have eroded any trend toward crisp stylistic differences in the *shuba* garments made by different groups. In contrast, male clothing appears to be characterized by more localized patterns of vertical transmission and branching descent, which suggests that these items of material culture may be performing different social and symbolic roles. It is possible that men signal their personal identity via different media and that variations in their garments represent more general design differences between north and south (e.g., in length and materials), while differences may also relate to the conservatism and vertical transmission of general clothing design within the different communities. Finally, while there is a broad distinction between male and female clothing in the mode of transmission, the female *sakh* also follows a more branching pattern of descent. Overall, we can suggest a more generalized set of stylistic distributions that are only partly characterized by distinct frontiers, a conclusion more in line with Welsch and Terrell's (1998) concept of broader "communities of culture."

This pilot study of northern Khanty clothing could be extended in several directions. First, formal cladistic analysis could be conducted on the data sets that appear to have a signal for branching descent, and the kinds of historical associations between these lineages could also be explored (Jordan and Mace 2006). Second, the present study focuses on a "female" domain of craft activity, while further work could document variations in other technologies—for example, ski, sledge, or boat designs. These are more strongly associated with the male sphere

of activity, which could have generated different transmission dynamics. While skis have a much deeper history in the region, the distinctive herders' sledges appear to have been adopted by the Khanty en masse from the Nenets, as part of the wider take-up of the "package" of reindeer pastoralism (Federova 2000, 123). Third, periods of ethnographic fieldwork in the communities could generate more detailed information about the learning of craft skills and the broader social and cultural contexts in which clothing is created and displayed, as well as the ways in which these contexts generate different kinds of strategies and motivations that eventually impact on longer-term material culture diversity. Fourth, the chapter has highlighted a series of relationships among material culture variability, demography, interaction patterns, and kinship, all of which could provide "real-world" inspiration for simulation studies that explore in more detail how these variables might interact through time to create different configurations of cultural diversity.

CONCLUSION

This chapter has argued that more studies of macroscale cultural transmission need to move beyond the mapping stage of analysis and combine independent knowledge about demography, ways of life, and kinship within a broadly evolutionary framework in order to develop fuller understandings the processes affecting "descent with modification" in material culture data sets. While the case study illustrates the potentials of the approach, the results also demonstrate how more attention needs to be directed to the "active" social and symbolic roles played by material objects in specific settings in order to understand how short-term decisions and strategies actively contribute to larger-scale patterns of cultural diversification.

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NOTE

1. The core data set was collected by A. M. Siazı between 1970 and 2000, a period coinciding with rapid oil and gas development in the region that drew in floods of Russian settlers and led to major disruptions in the traditional hunting, herding, and fishing ways of life (Siazı 2000, 5). Industrialization was preceded by the later Soviet period (1960–1980), which saw attempts to “wash out” cultural differences among various nationalities in the USSR and led to youth being “scornful/disdainful” of traditional native culture and decorative art. In recent years, Siazı (2000, 5) has noted the reverse trend as Khanty intelligentsia have sought to “preserve” and “resurrect” traditional culture. Produced in these cultural and political contexts, the overarching goal of Siazı's monograph was to record traditional forms and recent innovations in northern Khanty decorative art. The study draws on a rich vein of material from the middle and latter part of the nineteenth century (e.g., the Ahlqvist expeditions of 1858 and 1877; Sirelius's collections published in 1904; Rudenko's 1909–1910 study of Lower Ob' garments recovered from burial contexts dated to the 1850s, including “concrete” examples of clothing and footwear, published in German in 1970), as well as a full century of detailed work by various Soviet-, perestroika-, and post-Soviet era scholars. The monograph also draws on

Siazı's own knowledge of craft traditions—she grew up in a family of reindeer herders and received training from her mother, who was a master seamstress in the production of ornamental wares. Siazı's adult life has been dedicated to studying and “preserving” national craftsmanship, and the published study is based on analysis of over nine hundred items from across the Lower Ob' region.

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SIX

Tangled Trees

MODELING MATERIAL CULTURE EVOLUTION AS HOST–ASSOCIATE COSPECIATION

Felix Riede

EVOLUTIONARY biologists have long been aware that species are connected in complex and reciprocal ecological as well as evolutionary relationships with one another. In evolutionary time, such linked relationships produce linked phylogenies that, at least to some degree, reflect the evolutionary history of all organisms involved (Page 2003a). The study of long-term coevolution is part of the wider project of understanding the history of life through the construction of phylogenies and a battery of different methods is now available (e.g., Brooks and McLennan 1991; Page 2003b), many of which have been implemented in popular—and often free—software packages (see, e.g., <http://taxonomy.zoology.gla.ac.uk/rod/rod.html>).

The development of such quantitative approaches to long-term coevolution had its origin in molecular evolutionary studies (Goodman et al. 1979), but soon after they were also used to explore biogeographic issues (Humphries and Parenti 1986; Page 1988; Nelson and Platnick 1981) as well as host–parasite coevolution (Hafner

and Page 1995; Page 1990b, 1993, 1994a, 1994b, 2000; Page and Charleston 1997a, 1997b, 1998; Page and Cotton 2002; figure 6.1). In fact, Page and Charleston (1998, 356) have argued that the general approach and the computational procedures underlying it are applicable to a whole range of “historical associations.” In anthropology and archaeology, historical associations are ubiquitous, too, and by employing phylogenetic methods, archaeologists and anthropologists have made considerable headway in quantitatively understanding past societies and their evolution (e.g., Collard, Shennan, and Tehrani 2006a, 2006b; Mace, Holden, and Shannan 2005; O’Brien and Lyman 2000a; O’Brien et al. 2003). Yet, it remains unclear to what extent “descent with modification” (within one lineage) can be linked with “association by descent” (across two or more lineages; Jordan and Mace 2006).

In this chapter, I would thus like to explore in somewhat greater depth the salient points of contact between “historical associations” in biological and cultural evolution. The argument

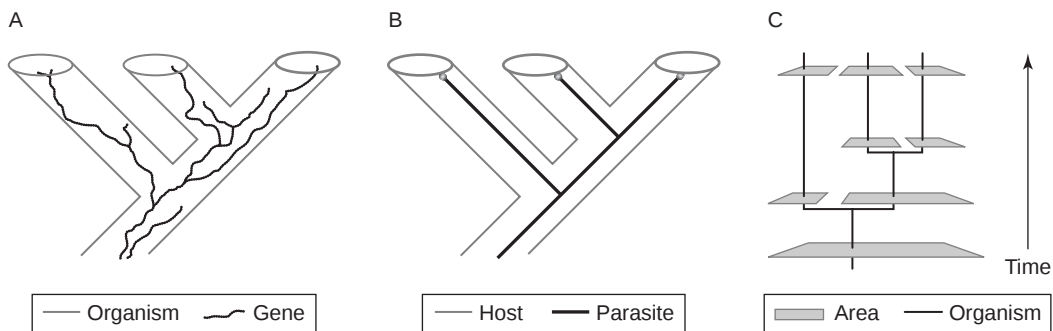


FIGURE 6.1 The three types of historical associations found in the biological world: (1) organism–gene, (2) host–parasite, and (3) clade–area relations. Adapted from Page and Charleston (1998, 356).

presented rests on three premises, one conceptual and two methodological:

- The relation of humans as biological entities and culture can be understood as one of host and associate (e.g., Brodie 1996; Cullen 1993a, 1993b, 1995, 1996a, 1996b; Dawkins 1976; Dennett 1995; Sperber 1996).
- Useful Darwinian models of short- to medium-term cultural evolution can be derived from quantitative epidemiology (e.g., Boyd and Richerson 1985; Durham 1991; Feldman and Cavalli-Sforza 1976; Kendal and Laland 2000; Lumsden and Wilson 1981).
- Long-term cultural evolution as seen in the archaeological record can be modeled using phylogenetic approaches (e.g., Lipo et al. 2006; Mace et al. 2005; O’Brien et al. 2003).

If these three premises can be shown to be robust, an application of *cospeciation* (or *cophylogeny*) models rather than *coevolution* models to archaeological questions is warranted because “cospeciation is coevolution that occurs in macroevolutionary time” (Page 2003a, 2; see also Brooks and McLennan 1991). Microevolutionary models are at the heart of gene-culture coevolution approaches (Boyd and Richerson 1992), but it has been argued that for archaeological problems, macroevolutionary models are analytically more appropriate (Lyman and O’Brien 2001). It is important to remember, too, that the degree to which a lineage displays cladogenetic patterns

depends on both the evolutionary processes and forces at work (e.g., the amount of variation, the strength of selection, the degree of isolation, etc.) and also on how the units of analysis (i.e., the taxa) are defined. While the importance of particular evolutionary forces will usually emerge only *after* an analysis has been conducted, the taxonomic units must, at least initially, be defined *prior* to analysis. Biologists (e.g., Ereshefsky 1992; Hull 1965, 1978, 1987; Lewontin 1970) have grappled long since with issues of unit definition, and recent efforts in archaeology have also made some headway (Dunnell 1995; Ramenofsky and Steffen 1998). However, general discussions of unit definitions for evolutionary archaeological analyses are lacking.

This chapter is divided into two parts. In the first part, a brief discussion of archaeological taxonomic units and their definition sets the stage for an exploration of the conceptual premise of linked cultural evolutionary dynamics. Although some archaeologists have argued that human culture can be conceptualized as parasitic to its carriers (especially Cullen 1993a, 1993b, 1995, 1996a, 1996b), it is argued here that any demonstrable historical association between the sets of artifacts studied suffices to warrant an attempt at applying cophylogenetic methods. There is in fact no need to resort to “bizarre” (Ingold 1993, 195) theories of cultural viruses: *If* two or more artifact lineages display cladogenetic evolutionary patterns, and *if* the processes of social information transmission that underlie these artifact lineages are somehow

linked—through, for instance, the context of their transmission, their use context, or as part of multicomponent artifact systems—then cophylogenetic patterns should emerge. In line with the discussion of Page and Charleston (1998), cospeciation models and their attendant methods are *in principle* applicable in any case where sets of phylogenies are linked in their evolutionary dynamics, no matter whether these phylogenies are based on morphological, genetic, or artifact data. The degree to which given lineages do show cophylogenetic patterns then becomes an empirical question.

The second part of the chapter presents the rationale of cospeciation analysis and a brief case study using the coevolution of European table knives and forks from the sixteenth to the twentieth century (Brown 2002a; Himsforth 1953; Lassen 1960; Moore 1999; Singleton 1973). This case study serves to illustrate one possible approach that implements a cophylogenetic approach to material culture change based on historical descent. The potential benefits are clear: Studying only one aspect of a given social group's material culture repertoire, such as knives or projectile points will inevitably yield a very limited view of the "total" history of this group, even if this particular artifact type is in some sense historically important. Cospeciation models thus offer the possibility of exploring the historical dynamics of different artifacts, such as knives *and* forks or projectile points *and* ceramics within one archaeological culture without relinquishing quantitative and phylogenetic rigor.

PART ONE: ARCHAEOLOGICAL TAXONOMIC UNITS AND HISTORICAL ASSOCIATION

In his discussion of how fossil hominins and Palaeolithic stone tools relate to one another, Foley (1987) suggests the use of archaeological taxonomic units (ATUs) defined at the appropriate level of (technological and geographic) resolution. More recently, Gamble et al. (2005) similarly attempted to relate archaeological technocomplexes to population genetic units in the

context of the Late Palaeolithic recolonization of Europe. These ATUs are intended to be the "cultural counterpart to the operational taxonomic unit (OTU) of biology and evolutionary science" (Gamble et al. 2005, 195), and their purpose is to circumvent the pitfalls of using traditional typologically defined archaeological units for Darwinian archaeological analysis (Lyman and O'Brien 2003; O'Brien and Lyman 2004; O'Brien et al. 2002). Despite their use of evidently evolutionary units, Gamble et al. (2005) stop short of employing evolutionary methods to analyze their archaeological data set. Unless they are underwritten by some kind of evolutionary rationale, taxonomies remain inert classification exercises (figure 6.2). Instead, within a cladistic approach to archaeology, taxonomic units can be defined through their character trait composition, following O'Brien and Lyman (2000a; O'Brien et al. 2002). It should then be possible to track higher-order ATUs up the cladogram; each monophyletic clade could be defined as one ATU. Traditional typological divisions of the same material may or may not map onto such cladistic unit definitions.

Socially transmitted information is complex and extremely rich in semantic content, and any given culture will harbor a plethora of "learning lineages" (Harmon et al. 2006, 209), some of which will be expressed through material culture. Within a social group, information will be transmitted differentially, according to gender, age, rank, occupation, and such (e.g., Shennan 1996). In addition, the use-lives and hence "generation lengths" of craft items vary, and with this the potential for evolutionary change (i.e., how much diversity can be introduced into a lineage and how fast change can occur) will differ from lineage to lineage. Architecture, for instance, often outlasts even biological generations, while items such as pots or arrowheads go through many "generations" of production and reproduction within the lifetime of their maker. These differences in evolutionary potential for change between different facets of craft production within the same cultural group may give rise to a "dissonance" (Fletcher 1996, 61)

	Equivalent	Examples from Gamble <i>et al.</i> (2005) > <i>this paper</i>
ATU1	Period	Palaeolithic, Mesolithic, > <i>Early Modern European</i>
	Sub-period	Early Mesolithic, > <i>16th Century</i>
ATU2	Techno-complex/ Culture	Aurignacian, > <i>Table Cutlery</i>
	Culture/ Industry	Upper Magdalenian, > <i>Northern European Table Cutlery</i>
	Industry/ assemblage	Magdalenian IV, > <i>Sheffield Industrial Tradition</i>
ATU3	Artefacts/ type fossils	Navettes, Mouilah points, > <i>Knives, forks</i>
	Attribute	Scalar retouch, truncation, > <i>Scimitar blades, rivetting, handle termination</i>

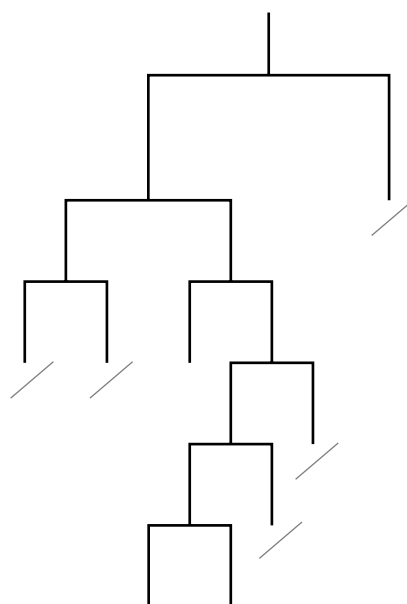


FIGURE 6.2 Gamble *et al.*'s (2005) list of archaeological taxonomic units juxtaposed to a cladogram with examples from Gamble *et al.*'s original discussion and potential candidates for ATUs of the present study. Although these recent discussions of ATUs are useful, it is not made sufficiently clear that the higher-order taxonomic units emerge out of lower-order constituents: The taxonomy must be read from bottom to top, rather than from top to bottom. If a phylogenetic rationale is adopted, higher-order ATUs can be defined as monophyletic clades along the cladogram or as "components" (see text).

between the phylogenetic signals of each lineage. We should not, for example, expect ceramic and flint technology to evolve at the same rate or follow the same pattern, because each lineage will be responsive to differences in their transmission and use context. Exploring these differences as reflected in each lineage's phylogeny may then reveal interesting insights into the kinds of forces that shape cultural evolution *within* a given group.

The use of cophylogenetic models and methods may therefore take artifact phylogenies beyond the investigation of single lineages and toward a better understanding of the biocultural evolutionary forces at work within past groups. An important step toward successfully addressing questions of long-term coevolution between human biology and culture or between different aspects of human culture (material or linguistic) is selecting the appropriate ATUs for the task at hand. Page and Charleston (1998) have provided the overarching rationale for a phylogenetic approach to such coevolution. They argue

that a variety of coevolutionary scenarios can be treated as largely identical from a methodological point of view and that phylogenetics offers a useful tool for formally exploring coevolution scenarios. The phylogenies used can variously be based on morphological, molecular, linguistic, material culture, or behavioral data, and the degree to which they exhibit congruence and the reasons for why they do or do not tell the same stories must be evaluated on a case-by-case basis. Here, an approach to long-term cultural coevolution is presented using the tree reconciliation methods from an approach known as component analysis.

PART TWO: HISTORICAL ASSOCIATIONS IN CULTURE AND THE EVOLUTION OF EUROPEAN CUTLERY

Component analysis is one of the techniques often employed in the study of long-term coevolution between biological systems (Nelson and Platnick 1981; Page 1990a). On its basis a variety

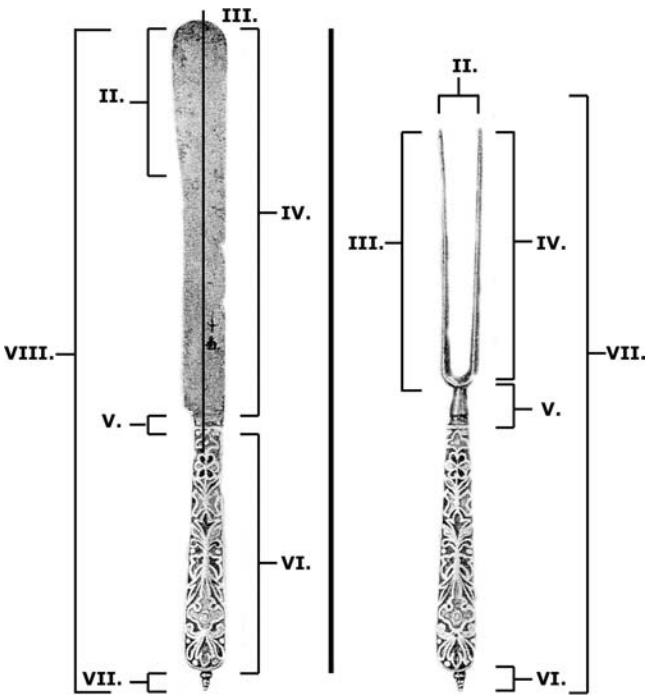
of coevolutionary issues can be addressed. In the biological world these include biogeography, gene–species relations, as well as host–parasite coevolution. Component analysis is a method of analyzing cladograms by dividing them into parts of analytical interest. Components refer to such usually monophyletic parts of a cladogram, and “each component may be conceived of as representing a group of kinds” (Nelson and Platnick 1981, 65). A small number of previous studies have tentatively explored the usefulness of tree comparisons, comparing trees generated using biological and cultural data (Robson Brown 1995) as well as sets of trees generated on the basis of different aspects of cultural information (Jordan and Mace 2006). In the latter study, Jordan and Mace restricted themselves to comparing the topologies (shapes) of their trees to randomly generated sets of trees. This kind of analysis can yield interesting insights about the coherence of cultural “cores,” but it relies on using the same (or at least the same number of) taxonomic units for the initial or fundamental tree building.

In contrast, the approach followed here departs from this constraint—equal numbers of terminal taxonomic units are not a requirement for component analysis—while accepting another: for reconciling phylogenetic trees, they must be fully resolved. Fully bifurcating resolution is rarely achieved in biological or cultural phylogenetic studies. Polytomies are caused by insufficient data resolution or real events—neither biological nor cultural evolution need proceed in a strictly bifurcating manner (Lewis, Holder, and Holsinger 2005; Maddison 1989; Walsh et al. 1999). European table cutlery was chosen as an example here for a variety of reasons. Data are readily available in collectors’ catalogs, and individual specimens are often conveniently dated to their year of manufacture, allowing for very high chronological resolution. Table cutlery was deemed to be well suited because the technological and social environment of cutlery manufacture and use are well known (Bailey 1927; Marquardt 1997; Singleton 1973; Wolfman and

Gold 1994; Brown 2002a; Moore 1999). In addition, from the seventeenth century onward, knives, forks, and to a lesser degree spoons were sold in sets, and this coupling of particular specimens (here taken as representative of the population) within a given set is indicative of “historical association.” This chapter is intended to be primarily a methodological exploration, and the main reason for the selection of this particular data set is its illustrative nature with regard to the cophylogenetic approach. However, a larger and rather more conceptual issue is also at stake. The term *evolution* is often used in the literature about cutlery design and manufacture, yet the art historical or art appreciative framework in which cutlery is usually considered is steeped in a typological view of the material (Ziman 2000; Ziman, Boden, and Wheeler 2002). It has already been suggested that evolutionary archaeological approaches are applicable to historical archaeology (O’Brien and Lyman 2000b), and perhaps phylogenetic analyses of design articles will put hypotheses of recent material culture evolution on a more quantitative basis.

Following the method of O’Brien et al. (2002), fifteen knife taxa and thirteen fork taxa were constructed. The characters and character states used are given in figure 6.3 and tables 6.1 and 6.2. Following taxon construction, cladograms were built using PAUP* 4.0b (Swofford 1998). Because the technologies employed in the manufacture of cutlery are complex, the Dollo parsimony setting was used (Gould 1970). Dollo parsimony stipulates that complex characters can be lost within a lineage but not reevolve in identical form. Although commonly referred to as Dollo’s law, according to Gould (2002, 902), it “only restates the general principles of mathematical probability for the specific case of temporal changes based on large numbers of relatively independent components.” While the general applicability of Dollo’s irreversibility law to biological systems is contested (e.g., Marshall, Raff, and Raff 1994; Wagner 1982), losses of *cultural* complexity may not be as rare, as is often assumed (Diamond 2005; Henrich 2004; Rivers 1926), and even

FIGURE 6.3 The characters selected for this analysis. The Roman numerals correspond to the characters listed in tables 6.1 and 6.2. The knife and fork pictured are specimens from around 1670 and adapted from Singleton (1973).



intentional revivals of old technologies or fashions rarely if ever lead to identical objects. While superficially similar cultural constellations certainly did evolve repeatedly, these are not true homoplasies (parallel evolution of

identical character states), nor are they true reversals if they occur in the same lineage. For instance, the large tanged points of the middle Upper Palaeolithic Gravettian, the so-called Font-Robert points, appear very similar to later

TABLE 6.1. *The Characters and Character States Used in the Analysis of Knives*

CHARACTER	CHARACTER STATE	CHARACTER	CHARACTER STATE
I. Raw Material	0. Iron 1. Silver 2. Steel 3. Stainless steel	V. Ferrule	0. None 1. Silver
II. Tip Shape	0. Triangular 1. Rounded	VI. Handle Cross-Section	0. Octagonal 1. Oval 2. Round 3. Rectangular
III. Blade Alignment	0. Offset (right) 1. Central	VII. Finial Shape	0. Finial 1. Blunt 2. Pistol grip 3. Convex 4. Drop 5. Rounded 6. Straight
IV. Blade Shape	0. Parallel sided 1. Diverging 2. Spatulate (spoon shaped) 3. Scimitar shaped 4. Converging	VIII. Length	0. 7 cm–8 cm 1. 8 cm–9 cm 2. 9 cm–10 cm 3. 10 cm–11 cm

TABLE 6.2. *The Characters and Character States Used in the Analysis of Forks*

CHARACTER	CHARACTER STATE	CHARACTER	CHARACTER STATE
I. Raw Material	0. Iron 1. Silver 2. Steel 3. Stainless steel	V. Ferrule	0. None 1. Silver
II. Number of Tines	0. 1 1. 2 2. 3 3. 4	VI. Finial Shape	0. Finial 1. Blunt 2. Pistol grip 3. Convex 4. Drop 5. Rounded 6. Straight
III. Tine Length	0. 2/3 of whole specimen 1. 1/4 of whole specimen	VII. Length	0. 6 cm–7 cm 1. 7 cm–8 cm 2. 8 cm–9 cm 3. 9 cm–10 cm
IV. Tine Angle	0. Straight 1. Angled		

tanged points of almost identical dimensions, such as Bromme points, which occur primarily along the northern European periphery during the Late Upper Palaeolithic. However, although they do both come from the ATU termed the European Upper Palaeolithic, the two point types are most certainly not historically related in any meaningful sense, and they can be distinguished on technological grounds, if the identifying characters are correctly chosen.

Both the knife and the fork data sets exhibit a very strong phylogenetic signal, and a randomization test shows that tree length is significantly shorter than expected (table 6.3). The analysis yields one and two equally parsimonious fully resolved trees for knives and forks, respectively.

TABLE 6.3. *Tree Statistics for the Most Parsimonious Knife and Fork Trees, Which Compare Favorably with Randomly Generated Trees*

	KNIVES	FORKS
Tree length	47	32
Consistency index	0.51	0.59
Retention index	0.85	0.86
Homoplasy index	0.49	0.41
Rescaled consistency index	0.43	0.51
<i>Randomization test:</i>		
Tree length	129	80
Standard deviation	15	10

Unfortunately, not enough data were available for spoons. Bootstrapping gave branch support levels of generally between 60 and 99 percent. Given that all specimens come from cutlery makers associated with the Sheffield tradition (Singleton 1973), such a strong phylogenetic signal is not unexpected. All trees (figure 6.4) were rooted using the oldest specimen (dated 1580) taken to represent an “ancestral” form.

In turn, these trees were reconciled using the TreeMap and GeneTree software packages (Page 1994a, 1998). Two taxa were taken to be associated when they had been sold in a set. The basic output consists of a so-called tanglegram (figure 6.5), which juxtaposes the two cladograms and plots the associations between terminal taxa. It is a useful tool for visually assessing the differences in branching pattern between the trees. Furthermore, the reconciled tree incorporates information from both original trees and provides a measure of the extent to which the two lineages have diverged. Using a model of possible processes that underlie the incongruence between trees allows a quantification of optimality criteria for tree reconciliation (table 6.4). Reconciliation will minimize the costs of mapping associated components onto one another, and the costs of these reconciliation actions can be varied from analysis to analysis. In the default setting (the one used

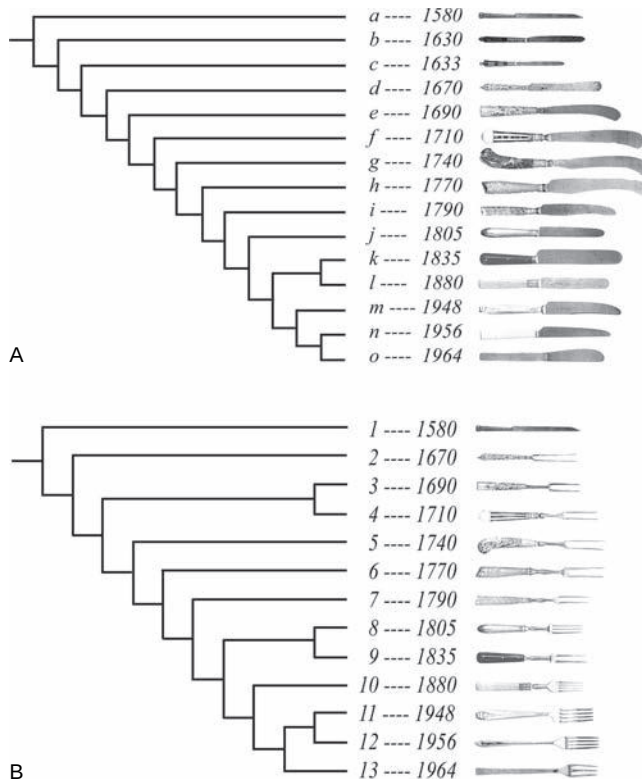


FIGURE 6.4 The most parsimonious cladogram for European table knives (1) and one of the two most parsimonious cladograms for the associated forks (2). The labeling conventions follow Page and Charleston (1997b), denoting the host taxa with lowercase letters and the associate taxa with Arabic numerals. Behind each taxon label is the year of manufacture for each specimen (after Singleton 1973). The cladograms are rooted using the oldest specimen; note that the forks outgroup is actually a knife as these were used for spearing prior to the invention of forks (i.e., they acted as single-pronged forks) and were also often sold in pairs (Mitchell 2002).

The topologies of the two trees reflect well how the evolution of forks (the associate) tracks the evolution of knives (the host), which in turn reflects—at least to a degree—the general accounts given of the change in table cutlery design during this period (Brown 2002c). The increasing structure in both trees around 1800 may be related to the introduction of electrolysis, which made cheaper silverlike raw material available to many manufacturers and stimulated a diversification in production and design. As Brown (2002c, 16) notes, “Throughout the nineteenth century the market for cutlery . . . expanded greatly, with services becoming larger and more varied in the number of items”; this is reflected in the greater diversity of raw materials and design templates used. Around the same time, dining habits also changed and the use of cutlery became more widespread among the middle classes of Europe (Brown 2002b; Day 2001; Moore 1999). In addition, more specialized forms of knives and forks for particular dishes began to be marketed and used.

However, this cladistic view of European knife evolution also diverges in some respects from art historical accounts. The knife tree in (1) appears to document a relatively gradual and incremental change in design and technology, whereas Brown (2002c, 16) states that “after the middle of the eighteenth century, an abrupt change occurred in the evolutionary chain of the English knife due to the introduction of the French fashion in furniture and decoration.” It is possible that the (relatively small number of) characters chosen for this analysis are not suited for showing this “abrupt change” or, alternatively, that it in fact was a superficial change that did not substantially affect traditional design elements in the Sheffield cutlery industry.

here), duplications and losses will be minimized, whereas it is also possible to optimize only for duplications, assigning a zero cost and thereby effectively ignoring losses. Each reconciled pair will be associated with a particular score, the sum of the events needed to fit the as-

sociate into the host tree. This goodness of fit can be further assessed through a randomization test, where a set of trees is randomly generated using the same number of taxa as the original host tree. The total reconciliation cost of these random trees can then be compared

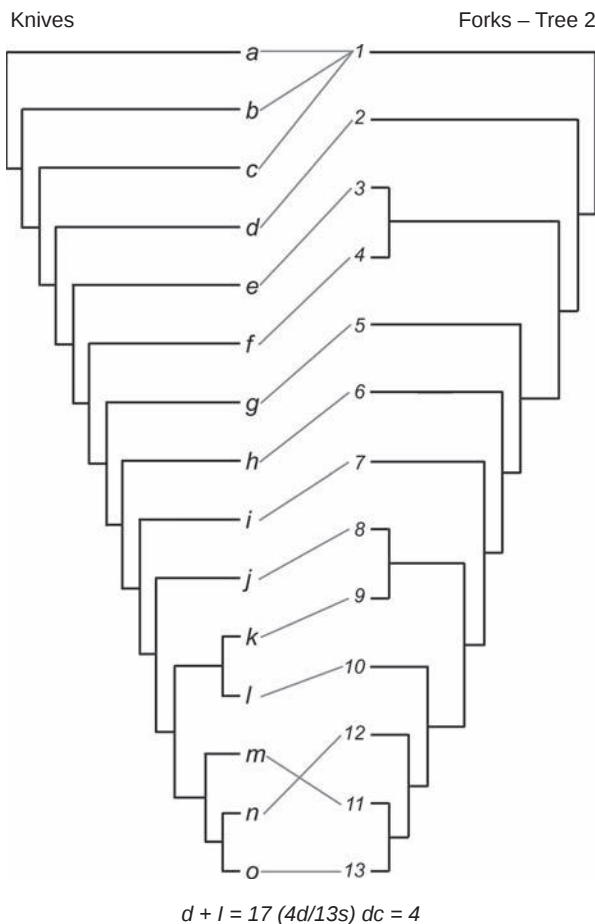


FIGURE 6.5 The “tanglegram” output produced by GeneTree (Page 1998), using the most parsimonious knife tree and the second of the two equal-cost fork trees. Different tree combinations can be evaluated using duplications (d) and losses (l) as cost parameters. The total cost ($d + l$) of the reconciliation is 17, and it requires four deep coalescences (dc).

TABLE 6.4. *Equivalent Processes of Biological and Cultural Cophylogeny Studies*

HOST-ASSOCIATE SYSTEM	CODIVERGENCE	DUPLICATION	HORIZONTAL TRANSFER	SORTING EVENT
Organism–gene	Interspecific coalescence	Gene duplication; deep coalescence	Gene transfer	Gene loss; lineage sorting
Host–parasite	Cospeciation	Within-host speciation	Host switch	Parasite extinction; “missing the boat”
Organism–area	Vicariance	Sympatry	Dispersal	Extinction
Organism–object	Direct horizontal or quasi-horizontal transfer; core cultural/adaptive technologies	Group fission without material culture change	Diffusion/ migration	Group extinction; stochastically caused break of transmission chain
Object–object	Linked technological, stylistic, or transmission systems; local adaptation	Cultural success; cultural “exaptation”	Stimulus diffusion or popularity	Loss of social or functional use context

SOURCE: Modified from Page and Charleston (1998).

with the reconciliation cost of the actual host tree. A heuristic search algorithm will retrieve from within the set of associate trees those with the lowest cost, and these trees will be maximally parsimonious in the sense of minimizing the total number of events required to explain the evolutionary history of the associate. For instance, if two lineages share an identical evolutionary history, reconciliation cost will be zero. Because tree reconciliation aims to preserve all the historical information contained in the input tree, the reconciled tree or trees are likely to be complicated, depending primarily on the degree to which the analyzed lineages have diverged, the number of equally parsimonious trees for each lineage, and the extent to which associations are shared across taxa. It is desirable to constrain the input as much as possible as the number of equal-cost reconciliations rises sharply with the number of input tree combinations. In addition, the utility of this approach is at present constrained by the need for fully resolved input trees and the inability of taking account of horizontal associations (i.e., gene transfer ~ contact). However, as Page and Charleston (1997b, 63) note, “the mapping and construction of reconciled trees is consistent for polytomous trees” and can potentially be incorporated into future releases of the appropriate software (see <http://evolve.zoo.ox.ac.uk/software/TreeMap>). With regard to horizontal associations, experimental versions of TreeMap (Charleston and Page 2002) are able to accommodate them, producing “jungles” instead of trees (Charleston 1998; Charleston and Perkins 2003).

CONCLUSION

It is suggested here that component analysis could be a useful further avenue for evolutionary archaeologists to explore if the phylogenetic study of culture is to be taken beyond single cladograms. Hafner and Page (1995, 79) suggest that “component analysis is sufficiently general to be applied to any historical association.” Many historical processes, whether in biology (Mirkin et al. 1997), at the interface between biology and

culture (Foley 1987, 2002; Robson Brown 1995), or between different facets of culture (Jordan and Mace 2006) are made up of multiple lineages of information transmission, and these lineages may be linked through historical association. However, the constituent trees respond to different evolutionary pressures and dynamics and therefore exhibit different branching patterns. Although rather complex in implementation and interpretation, the cophylogenetic approach presented here offers one possible means of operationalizing Gamble et al.’s (2005) archaeological taxonomic units. Microevolutionary everyday processes of toolmaking, situated within their rich social context, give rise to archaeologically observable technological lineages (Riede 2006). These lineages can be analyzed using cladistic methods, and higher-order ATUs such as regional facies or cultures can be defined cladistically as monophyletic clades. When two or more artifact cladograms from the same cultural context are available, component analysis serves to visualize the relationship among them. Historical association of archaeological material culture lineages could, for instance, be defined through their co-occurrence in undisturbed contexts and the reconciled tree scores understood as the extent to which the two lineages have diverged.

At present, the inability of the available software packages to deal with trees that are not fully resolved still militates against a more productive application of tree reconciliation approaches to cultural data. A further exploration of this approach is equally hampered by a lack of cultural phylogenies that are historically associated (see Collard et al. 2006a and 2006b for an overview of currently available cultural phylogenies). This chapter has taken some tentative steps toward outlining the theoretical foundation for an extension of the cospeciation approach to cultural data and draws attention to the ready availability of the appropriate, albeit still limited, software. In exploring the quantitative study of historical association, it is important to keep in mind that the analogy between the different kinds of historical associations is

merely a heuristic tool. The argument is not that the processes are closely analogous but that the *patterns* produced by these very different processes are in fact very similar and can therefore be studied using similar techniques (see Page and Charleston 1998). Future work can build on this foundation by exploring case studies of historically associated kinds of material culture and thereby further refine the approach.

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ONLINE SOURCES

<http://taxonomy.zoology.gla.ac.uk/rod/rod.html>
<http://evolve.zoo.ox.ac.uk/software/TreeMap>

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SEVEN

The Evolution of Material Culture Diversity among Iranian Tribal Populations

Jamshid J. Tehrani and Mark Collard

A WIDELY HELD view in anthropology suggests that the processes of cultural and biological evolution differ greatly. An early expression of this view can be found in Kroeber's 1948 volume *Anthropology: Race, Language, Culture, Psychology and Prehistory*. Kroeber suggested that

the course of organic evolution can be portrayed properly as a tree of life, as Darwin has called it, with trunk, limbs, branches, and twigs. The course of the development of human culture in history cannot be so described, even metaphorically. There is a constant branching-out, but the branches also grow together again, wholly or partially, all the time. . . . A branch on the tree of life may approach another branch; it will not normally coalesce with it. The tree of culture, on the contrary, is a ramification of such coalescences, assimilations, or acculturations. (138)

More recent writers have evoked this contrast by likening cultural evolution to a “braided riverbed” (Moore 1994) or “entangled bank” (Terrell 1988) as opposed to the “family tree” model used to depict the relationships among species. In the last few years, this view has been challenged by a number of studies (e.g., Collard

and Shennan 2000; Gray and Jordan 2000; Tehrani and Collard 2002; O'Brien, Darwent, and Lyman 2001; Jordan and Shennan 2003; Collard, Shennan, and Tehrani 2006). Using methods of phylogenetic reconstruction developed by evolutionary biologists, these studies have sought to evaluate how well cultural patterns fit a branching, treelike model of evolution in which ancestral traditions split into new ones. The majority of these studies have failed to support the suggestion that cultural evolution is always more complex and intertwined than genetic evolution. Thus, instead of rejecting the family tree model out of hand, anthropologists should evaluate the contributions made by different evolutionary processes to patterns in the ethnographic and archaeological records on a case-by-case basis.

In this chapter, we aim to contribute to empirical research in this area by investigating the relative importance of branching and blending processes in the evolution of material culture diversity among tribal populations in Iran. Our study builds on a previous study in which phylogenetic methods were applied to a data set comprising decorative characters from textiles

produced by five Turkmen tribes between the eighteenth and early twentieth centuries, with a view to testing the braided riverbed/entangled bank model of cultural evolution (Tehrani and Collard 2002). We carried out two sets of analyses (Tehrani and Collard 2002). The first focused on artifacts produced prior to the colonization of Turkmen territories by Imperial Russia in the late 1800s, and we found that approximately 70 percent of the similarities among the tribes' woven assemblages in this period can be accounted for by the family tree model. The second set of analyses focused on artifacts produced after 1881. The results of these analyses also suggested that the pattern of design variation is most consistent with the family tree model, although the percentage of resemblances among the tribes' weavings that could be accounted for by this model decreased to around 60 percent. Based on these two sets of results, we concluded that cultural evolution among the Turkmen over the last two hundred years was more compatible with the family tree model than the braided riverbed/entangled bank model.

Here, we seek to go beyond our earlier study (Tehrani and Collard 2002) and provide a more comprehensive understanding of material culture evolution among the tribes of western Central Asia. An important reason for pursuing this goal is that, for most of their history, Turkmen tribes enjoyed a level of autonomy from state governments that was unusual for tribes in the area (see, e.g., Irons 1974; Tapper 1991). This appears to be mainly due to the inaccessibility of the remote, frontier regions that they inhabited. Given that we (Tehrani and Collard 2002) found evidence that branching processes became less important in Turkmen cultural evolution after they were incorporated into the Russian Empire, it is possible that cultural evolution among tribes that have a longer history of interacting with state governments may be more consistent with the braided riverbed/tangled bank model. With this in mind, the data set we analyze includes data taken from textiles produced by several Iranian tribal groups who were less remote and less

autonomous than the Turkmen as well as data from textiles created by two Turkmen tribes.

BACKGROUND

Woven textiles are ubiquitous in the material culture assemblages of Iranian tribal groups. Produced exclusively by women, who typically begin learning to make them between the ages of six and ten (Irons 1980; Amir-Moez 2002; Beck 1991; Tehrani 2004), they fulfill a wide range of functions, from the mundane and utilitarian to the ornamental and ceremonial. Among the most commonly made items are colorful hand-knotted rugs, saddlebags, animal trappings, packing bands, salt bags, tent canopies and decorative hangings, articles of clothing, and small pouches for carrying cutlery. One reason for the popularity of woven textiles in these groups is that a textile-based material culture is well suited to the nomadic-pastoralist lifestyle that was pursued by most tribal communities in Iran until recently (Irons 1980; Digard 1981, 2002; Mortensen and Nicolaisen 1993; Amir-Moez 2002; Tapper 2002). Objects woven from wool are relatively easy to carry on seasonal migrations, because they can be folded or rolled. Equally importantly, the materials and equipment required for weaving are straightforward for tribeswomen to obtain locally and transport between camps.

Iranian tribal weavings have long fascinated Western collectors (Spooner 1986; Helfgott 1994), and a large body of literature is dedicated to understanding the sources and relationships of Iranian tribal weaving traditions (e.g., Housego 1978; Eiland 1982, 1987; Thompson 1980, 1983; Opie 1981, 1992; Mallett 1998; Parham 1996; Stone 2004). However, research in this field has been hindered by two problems in particular. One is that textiles are fragile and liable to decay rapidly. The consequence is that few ancient textiles have the potential to provide insights into the early history of weaving. Moreover, even when such discoveries do occur (e.g., Rudenko 1970), there is invariably

insufficient evidence to make any direct link between tribal populations in the distant past and those of today. The other problem is that many of the theories that have been put forward by oriental rug specialists are highly speculative because they are based on evidence that has been selected according to predetermined criteria of “authenticity” (Spooner 1986).

Obviously, little can be done about the first of the aforementioned problems. However, we believe that it is possible to overcome the second by adopting a more rigorous approach to the reconstruction of Iranian tribal weaving traditions. More specifically, we advocate employing what is now the most widely used technique for reconstructing phylogenetic relationships among species and other taxa—cladistics (Quicke 1993; Kitching et al. 1998).

Based on a null model in which new taxa arise from the bifurcation of existing ones, cladistics defines phylogenetic relationship in terms of relative recency of common ancestry. Two taxa are deemed to be more closely related to one another than either is to a third taxon if they share a common ancestor that is not also shared by the third taxon. Exclusive common ancestry is indicated by shared evolutionarily novel or “derived” character states. Two taxa are inferred to share a common ancestor to the exclusion of a third taxon if they exhibit shared derived character states that are not also exhibited by the third taxon.

In its simplest form, cladistic analysis proceeds via four steps. First, a character state data matrix is generated. This shows the states of the characters exhibited by each taxon (e.g., presence/absence of a chin). Next, the direction of change among the states of each character is established. Currently, the favored method of accomplishing this is outgroup analysis (Arnold 1981). This entails examining a close relative of the focal taxa to determine which character states are derived (those found only among the focal taxa) and which are ancestral (those shared by one or more of the focal taxa and the outgroup). Having determined the probable direction of change for the character states, the next step is to construct a

branching diagram of relationships for each character. This is done by joining the two most derived taxa by two intersecting lines, and then successively connecting each of the other taxa according to how derived they are (figure 7.1). Each group of taxa defined by a set of intersecting lines corresponds to a clade, and the diagram is referred to as a cladogram. The last step is to compile an ensemble cladogram from the character cladograms. Ideally, the distribution of the character states among the taxa will be such that the character cladograms imply relationships among the taxa that are congruent with one another. Normally, however, some of the character cladograms will suggest relationships that are incompatible. This problem is tackled by generating an ensemble cladogram that is consistent with the largest number of characters and therefore requires the smallest number of ad hoc hypotheses of character appearance to account for the distribution of character states among the taxa.

In using cladistics to investigate Iranian tribal material culture diversity, we are following a precedent set by a number of previous studies (e.g., Foley 1987; Robson-Brown 1996; Foley and Lahr 1997, 2003; Collard and Shennan 2000; Gray and Jordan 2000; O’Brien et al. 2001, 2002; Holden 2002; Tehrani and Collard 2002; O’Brien and Lyman 2003; Rexová, Frynta, and Zrzavý 2003; Cochrane 2004; Collard et al. 2006). This approach is rooted in the observation that the problem of reconstructing human population history from cultural data shares features with the problem of reconstructing the evolutionary history of a group of species (Kirch and Green 1987, 2001). In both cases, the key challenge is to distinguish similarities resulting from shared ancestry (homologies) from similarities due to mechanisms other than shared ancestry (homoplasies). While the processes responsible for generating biological and cultural homologies are not the same (gene transfer vs. cultural transmission), and those responsible for generating the majority of biological and cultural homoplasies probably also differ, the problems

	Character 1	Character 2	Character 3	Character 4	Character 5	Character 6
TAXON A	1	1	0	0	0	1
TAXON B	1	1	1	1	0	1
TAXON C	1	1	1	1	1	0
TAXON X	0	0	0	0	0	0

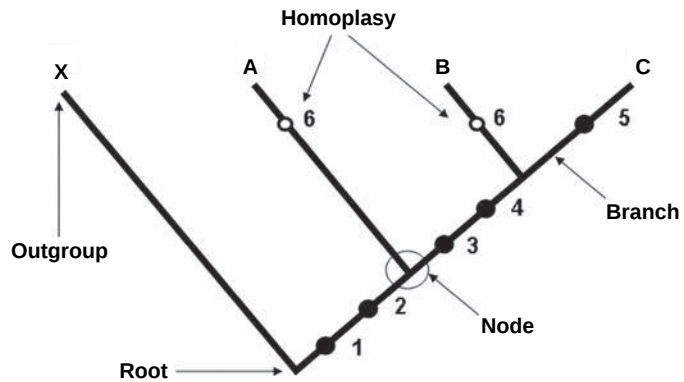


FIGURE 7.1 Example data set and cladogram derived from it.

of establishing relationships of descent among cultural groups and among biological taxa are sufficiently similar in terms of epistemology and ontology to warrant the application of phylogenetic methods to cultural data. Most significantly, in both cases a model is sought that explains the distribution of resemblances among a group of taxa in the absence of prior knowledge of how those resemblances arose. The bifurcating tree model is used because it is the simplest and therefore the most defensible way of linking taxa together. Once a tree model has been generated for a group of taxa, it is possible to classify the similarities among them as homologous or homoplastic. Homologous similarities support relationships that are compatible with the tree model, whereas homoplastic ones suggest relationships that conflict with it.

Application of cladistics to the problem of elucidating the sources and relationships of Iranian tribal weaving traditions is facilitated by the nature of the woven artifacts. Like biological phenotypes, Iranian tribal textiles are morphologically complex and can be most accurately

described by identifying the specific traits they exhibit. For example, the face of the saddlebag shown in figure 7.2 incorporates several distinct weaving techniques (pile weaving, weft-faced plain weave, and extra-weft wrapping) and a series of integrated but isolable motifs. It is evident from the literature (e.g., Housego 1978; Thompson 1980; Opie 1992; Mortensen and Nicolaisen 1993) that traits such as these vary considerably among different tribal groups. For example, analyses of textile structures have revealed that there are numerous variations in the technique of pile knotting, in which patterns are generated by the cut ends or “tufts” of dyed yarns woven across the warp (e.g., Thompson 1980; Mallett 1998). The pile weavings of different tribes can be differentiated by a number of criteria such as knot density, whether knots are symmetrical (looped fully around two warp threads) or asymmetrical (looped fully around one warp thread and passed underneath another on either the left or right side), and the relative displacement of alternate warp threads. Flat-woven structures are similarly diverse,

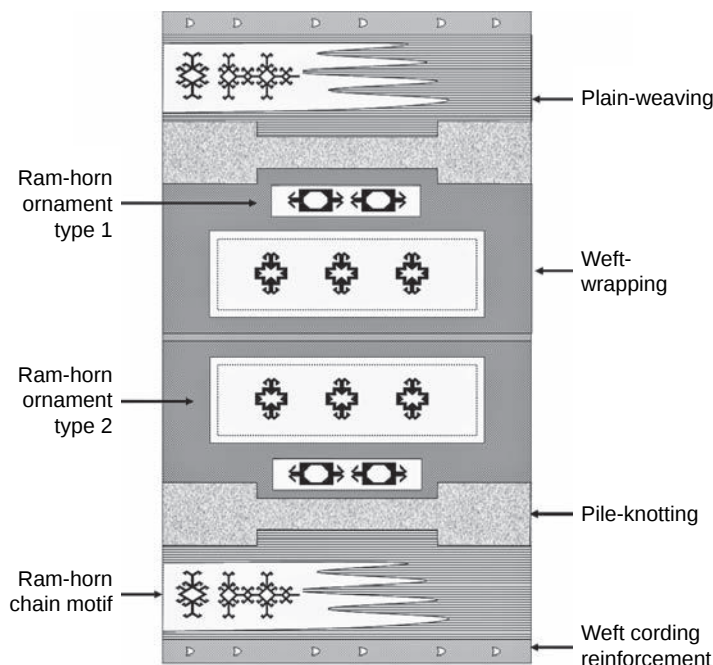


FIGURE 7.2 Saddlebag made by a weaver from the Bakhtiari tribe. Three techniques (bold print) were used to weave the bag face: the foundation consists of weft-faced plain weave in alternating stripes of red and black; the central panel comprises designs (e.g., rooster, infinite knot) woven onto the foundation by extra-weft wrapping; and the end panels are woven in a rough pile weave, with designs rendered by the tufts of the pile (e.g., palmette).

while almost every motif used on tribal textiles can be linked to a large family of related designs (e.g., Stone 2004; Opie 1992). The detailed typologies of design, structure, and technique that have been developed by oriental textile specialists (e.g., Thompson 1980; Mallett 1998; Stone 2004) therefore provide a basis for identifying the characters and character states that are the basic units of cladistic analysis.

MATERIALS AND METHODS

The study focused on woven artifacts produced by four Turkic-speaking tribes and four Persian-speaking tribes. The former included two Turkmen groups, the Yomut and Tekke, and two

Azeri-speaking groups, the Qashqa'i and the Shahsevan, while the latter included the Baluch and three groups that employ dialects of Lori, a Persian language related to Kurdish (Grimes 2002): the Bakhtiari, the Boyer Ahmadi Lor, and the Papi Lor. The geographic locations of tribes included in the study are shown in figure 7.3.

The tribes produce a wide range of woven artifacts, as well as some items that are made of felt (e.g., tent walls, caps, and cloaks) and basketry (e.g., containers, mats, and small cages for transporting poultry). The tribes' woven products were studied through material culture monographs (Allgrove 1976; Tanavoli 1985; Mortensen and Nicolaisen 1993; Konieczny 1979; Willborg 2002), museum collections (e.g., Mackie and Thompson 1980; Tzavera



FIGURE 7.3 Map of Iran showing the locations of the territories of the study groups.

1984), and field surveys conducted in western Iran in the summer of 2001 and spring of 2002 (Tehrani 2004).

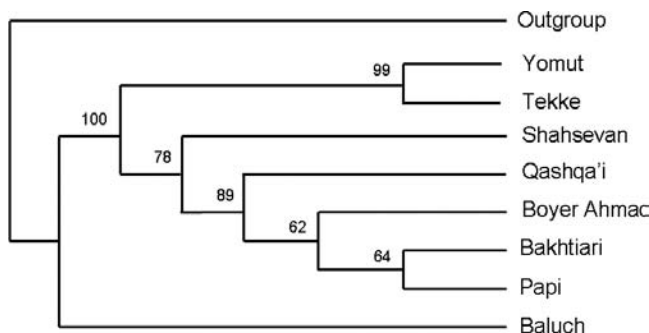
Textiles produced by Arab Bedouin of Jordan were also sampled (Weir 1976) in order to provide an outgroup for the analyses. The Bedouin are a useful outgroup for current purposes because, although they are geographically, culturally, and linguistically distinct from both the Turkish- and Persian-speaking Iranian tribes, their crafts are believed to constitute a related tradition based on the materials, techniques, and designs they use (Weir 1976).

A total of 150 characters were identified. They included techniques of preparation and fabrication (e.g., spinning, knotting, etc.), the use of different materials (e.g., wool, goat hair, dyes, etc.), and decorative features (e.g., carpet designs, border patterns, etc.). Characters were defined in such a way that they could be scored as either present or absent.

After coding, the data set was subjected to a two-stage analysis. The aim of the first stage was to generate a cladogram or set of cladograms that best represented patterns of descent for the eight tribal assemblages. This was ac-

complished with the branch-and-bound search routine of the phylogenetics software program PAUP* 4 (Swofford 1998). PAUP* 4 was employed because it is widely used in evolutionary biology; its branch-and-bound search routine was selected because it is guaranteed to find the most parsimonious cladogram(s) for a given set of data (Swofford 1998).

The second stage of the analysis aimed to establish how well the most parsimonious cladogram accounts for the pattern of similarities and differences among the tribal assemblages. This was achieved with two goodness-of-fit measures—the Consistency Index and the Retention Index—and the phylogenetic bootstrap. The Consistency Index is a measure of how parsimonious evolution has been for a given combination of cladogram and data set; that is, it is a measure of the number of homoplasies in a data set (Kitching et al. 1998). A Consistency Index of 1.0 indicates that the data are perfectly congruent with the cladogram (i.e., the cladogram requires no homoplastic changes to be hypothesized), and homoplasy levels increase as the Consistency Index decreases toward 0. The Retention Index is a measure of the number of



homoplastic changes that a cladogram requires independent of its length (Farris 1989a, 1989b). A maximum Retention Index of 1 indicates that the cladogram requires no homoplastic change; and as the level of homoplasy increases, the index approaches 0. Whereas the Consistency Index and Retention Index measure the overall fit between the tree and patterns in the data set, the phylogenetic bootstrap is a technique for measuring support for individual clades (Felsenstein 1985; Sanderson 1995). It involves generating cladograms by creating fictional data sets the same size as the original by randomly re-sampling characters from the original data set with replacement a large number times (in this case, ten thousand) and calculating the percentage of replicates that support a given clade. Data sets that fit the bifurcating model with little conflicting signal will return high bootstrap support percentages and vice versa. As with the parsimony analysis, all three of the techniques described here were carried out in PAUP* 4.

The cladogram favored by the parsimony analysis is shown in figure 7.4. It suggests that the Yomut, Tekke, Shahsevan, Qashqai, Boyer Ahmad, Bakhtiari, and Papi share a common ancestor to the exclusion of the Baluch. The clade composed of Yomut, Tekke, Shahsevan, Qashqai, Boyer Ahmad, Bakhtiari, and Papi is then subdivided into two subclades. The first comprises two groups that speak similar dialects of Turkmen, a Turkic language: the Yomut and the Tekke. The second clade comprises a linguist-

tically heterogeneous group of tribes. The Shahsevan and Qashqai both speak Turkic languages. However, the latter are included in a clade with three Persian Lor-speaking groups: the Boyer Ahmad, Bakhtiari, and Papi. These three groups comprise a clade that excludes the Qashqai, suggesting their craft traditions are descended from a more recent common ancestor. Within this clade is a further subclade comprising the Bakhtiari and Papi.

assemblages. The least well-supported subclade consisted of the Boyer Ahmad, Bakhtiari, and Papi (62 percent). There was slightly more support for a subclade comprising the Bakhtiari and Papi (64 percent).

DISCUSSION

The Consistency Index, Retention Index, and the results of the bootstrap analysis indicate that there is a reasonably close fit between the data set and the cladogram, which suggests that branching processes have played an important role in generating the textile assemblages. According to the Consistency Index (0.60), roughly 60 percent of the resemblances among the assemblages can be accounted for by a family tree model. This result is very close to the one returned by the same measure of how treelike patterns of design variation are among contemporary Turkmen populations (CI = 0.61)

(Tehrani and Collard 2002). Thus, based on the results of these two case studies, it would appear that the regional patterns of material culture diversity among tribal groups in western Central Asia are largely, although not exclusively, the product of branching processes.

To put this apparent regional pattern in an even broader perspective, the Retention Index for the eight Iranian tribal textile assemblages can be compared with the Retention Indices obtained by Collard et al. (2006) from a large number of cultural (table 7.1) and biological data sets (table 7.2). The Retention Index is particularly useful for this type of comparative analysis because it is not affected by the number of characters or the number of taxa employed in a study. At 0.60, the Retention Index of the Iranian tribal textile assemblage cladogram falls well within the range of Retention Indices returned by the other cultural data sets, which is 0.42–0.78, and almost exactly matches

TABLE 7.1. *Comparison of the Retention Index Yielded by the Iranian Tribal Textile Assemblage Data Set with Retention Indices for 20 Cultural Data Sets*

DATA SET	RETENTION INDEX
Gulf of Georgia Salish food taboos and prescriptions	0.57
Neolithic pottery	0.71
Californian Indian basketry	0.71
Eastern North American projectile points	0.70
Coast and inland Salish cultural practices	0.63
New Guinea material culture	0.51
Turkmen weaving designs	0.44
Northwest Coast tribal religion and ritual	0.65
Early Christian doctrinal beliefs	0.61
Iranian tribal weavings	0.60
Northwest Coast archaeology	0.50
Pomo structures	0.52
Oregon Coast tribal puberty rites	0.55
Southern Sierra Nevada tribal death and mourning practices	0.48
Nevada Shoshoni tribal mutilations	0.78
Southern California tribal body- and dress-related practices	0.52
Yuman-Piman warfare-related practices	0.69
Apache-Pueblo houses	0.63
African cultural practices	0.42
Northern Paiute birth rituals	0.43
Northeastern Missouri projectile points	0.66

NOTE: Reported by Collard et al. (2006). The indices are ranked from highest to lowest, and the Iranian tribal textile assemblage Retention Index data set is highlighted in bold.

TABLE 7.2. *Retention Indices for Twenty-One Biological Data Sets*

DATA SET	RETENTION INDEX
Australasian teal mtDNA	0.94
Corbiculate bee behavior	0.94
Pelecaniforme bird behavior	0.84
Anoles lizards morphology	0.79
Primate behavior	0.73
Strepsirrhine primate morphology	0.72
Fossil hominid morphology	0.71
New World monkey morphology	0.70
Ungulate morphology	0.70
Phalacrocoracid bird mtDNA	0.65
Phocid seal morphology	0.60
Hawaiian fruit fly mtDNA	0.50
Hominoid primate cranial morphology	0.49
Carnivore mtDNA	0.47
Mammal mtDNA with emphasis on Malagasy primates	0.47
Carnivore mtDNA with emphasis on Malagasy taxa	0.47
Mammal mtDNA	0.44
Insectivore mtDNA	0.44
Lagomorph mtDNA	0.39
Hominoid primate soft-tissue morphology	0.38
Anolis lizard mtDNA	0.35

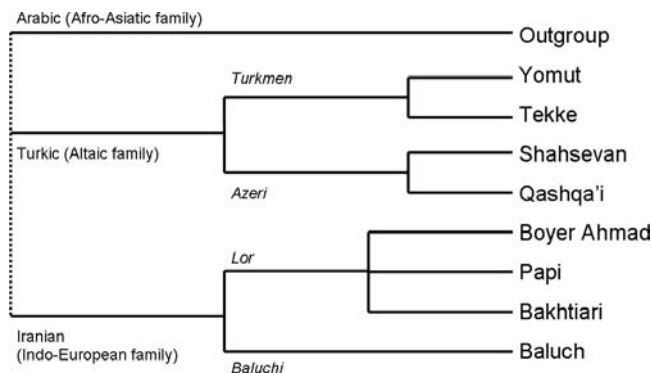
NOTE: Reported by Collard et al. (2006). The indices are ranked from highest to lowest.

the mean Retention Index of 0.59. Thus, the fit between the Iranian textile assemblage data set and the cladogram is not atypical for a cultural data set. In view of the long-standing assumption that cultural evolution is much more reticulate than biological evolution, it is perhaps more surprising that the Retention Index yielded by the Iranian textile assemblage data set is also close to the mean of the Retention Indices returned by the biological data sets, which is 0.61. Thus, the proportion of resemblances among the Iranian tribal craft assemblages that can be accounted for by inheritance from ancestral taxa is almost exactly the same as the average for related biological species.

Our results could be interpreted as supporting a model of cultural evolution that is based on speciation theory in biology (e.g., Mayr 1963). This model proposes that culture, along with genes and language, is acquired almost entirely by inheritance from ancestral populations and is only minimally influenced by con-

tact among neighboring groups (e.g., Durham 1990, 1992). However, like many other researchers interested in cultural evolution (e.g., Boyd et al. 1997; Shennan 2002; Jordan and Mace 2006), we consider this model to be too extreme because on the whole it seems that the ideas, skills, beliefs, and behaviors that are present in any given population are not as tight contained as genetic traits are in species. In the Iranian case, for example, many tribespeople speak languages originating thousands of years ago in Central Asia (e.g., Oghuz Turkic languages like Azeri or Turkmen), hold religious beliefs that arose in the Arabian peninsula several centuries ago (Islam), hunt with European-manufactured weapons (rifles), and consume vast quantities of a drink introduced into Iran by the British in the nineteenth century that derives from a plant first cultivated in China (tea) (Digard 2002). Therefore, we do not believe that these cultures should be considered equivalent to biological species in a

FIGURE 7.5 Diagram representing the linguistic relationships among the study populations. The Turkic-speaking groups divide into two branches, Turkmen and Azeri. The Persian-speaking groups comprise the Baluch, who speak a northwestern Iranian language, Balochi, and three groups who speak dialects of another northwestern Iranian language, Lori. (After Grimes 2002.)



literal sense. However, the strength of the phylogenetic signal that we recovered from the material cultural data set also rules out the entangled bank (Moore 1994) or braided riverbed (Terrell 1988) model, which proposes that culture comprises temporary collections of traits that are so ephemeral that it is impossible to retrieve any trace of branching descent (e.g., Terrell 2004).

This leaves two other possibilities. The first is that the craft phylogeny might represent what has been called a “core tradition” (e.g., Boyd et al. 1997; Shennan 2002; see also Rosenberg 1994). A core tradition represents a set of cultural traits that is relatively insulated from cultural, linguistic, and genetic exchange with other groups and therefore remains stable for a long period of time. The second possibility is that Iranian tribal craft traditions represent a “package” of cultural traits. The “multiple packages” model of cultural evolution (e.g., Boyd et al.; Shennan 2002) proposes that coherent cultural lineages do not always necessarily coincide with population histories. Some traditions may remain stable even when they are transferred across ethnolinguistic boundaries. A phylogeny for such a tradition may therefore reveal patterns of inheritance from ancestral groups, but it could also include information about how cultural traits spread among more distantly related populations.

To examine which of these models best explains the evolution of Iranian tribal craft traditions, we compared our cladogram with an estimate of the tribe’s linguistic affiliations

(figure 7.5; cf. Gray and Jordan 2000; Borgerhoff-Mulder 2001; Holden 2002). The comparison revealed that the division of the craft traditions of the Turkic-speaking groups into two separate lineages corresponded to the split between Turkmen speakers (the Yomut and Tekke) and Azeri speakers (the Qashqai and Shahsevan). This fits with the core traditions model of cultural evolution. The hypothesis that the assemblages of the Boyer Ahmad, Papi, and Bakhtiari share an exclusive common ancestor is also compatible with the model because all three speak Lori. However, it appears that these assemblages are more closely related to those of Turkic-speaking groups than they are to the Baluch assemblage, despite the fact that the Baluchi language belongs to the same Indo-Iranian northwestern Iranian family as Lori. This clade, which was found in 100 percent of the bootstrap cladograms, suggests that the craft traditions of the Lor-speaking Bakhtiari, Papi, and Boyer Ahmad are probably Turkic in origin. More specifically, the internal structure of the clade indicates an Azeri source, since the Bakhtiari–Papi–Boyer Ahmad clade is nested within a larger clade that contains the Qashqai and Shahsevan but excludes the Yomut and Tekke. It appears that the ancestral assemblage from which the three Lor-speaking groups’ craft traditions derive is the same one that gave rise to present-day Qashqai weavings, since these groups were linked by a clade excluding the Shahsevan that has high bootstrap support (89 percent). Ethnohistorical evidence and the tribes’ geographic distributions (figure 7.3) suggest that this common source was

most probably the Azeri-speaking tribes that migrated from the Caspian territories (which the Shahsevan continue to inhabit) to southwestern Iran more than five hundred years ago. The descendants of these tribes later formed the core of the Qashqai tribal confederacy that arose in the nineteenth century (e.g., Beck 1986; Amir-Moez 2002), but some were likely also absorbed by neighboring Lor-speaking tribes (cf. Barth 1961). Although the precise nature of the mechanisms through which the latter acquired their weaving skills requires further exploration, it appears that the structure of the craft traits cladogram reflects both inheritance from ancestral populations and transference across ethnolinguistic boundaries. Therefore, it appears that the multiple packages model of cultural evolution offers the best explanation for the origins and spread of weaving among tribal populations in Iran.

CONCLUSIONS

The case study that we have reported here adds further weight to the recent critique of conventional assumptions in anthropology and archaeology regarding cultural evolution. There is now strong reason to believe that, contrary to what most anthropologists and archaeologists currently assume, the relationships among cultural traditions can often be explained by a branching pattern of descent. The results of our analyses suggested that a majority of resemblances among tribal craft assemblages in Iran can be explained by such a model. However, as we pointed out at the beginning of this chapter, researchers should probably be cautious about generalizing about the processes involved in cultural evolution and consider the evidence for each case independently. Here we have shown that although the patterns in the Iranian tribal craft data set are in many ways typical of those in other cultural and biological data sets, the models required to account for these patterns might vary considerably. In this case, we have argued that a multiple packages model offers a better explanation for the evolution of material culture diversity among Iranian tribal groups

than a speciation model, an entangled bank model, or a core traditions model. However, we do not rule out the possibility that these and other models might apply in other cases. We suspect that future research in this field will demonstrate that we are still at a very early stage of understanding how patterns of cultural diversity evolve and how they relate to population histories, genetic patterns, and languages.

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EIGHT

Evolutionary Explanation and the Record of Interest

USING EVOLUTIONARY ARCHAEOLOGY AND DUAL INHERITANCE THEORY
TO EXPLAIN THE ARCHAEOLOGICAL RECORD

Ethan E. Cochrane

IN THE FIRST PART of last century, anthropologists and archaeologists such as Kroeber, Childe, and others suggested that in some instances material culture similarities in space and time could be explained by the passing of information between individuals. The kernel of this simple idea—people copy those around them—was quantitatively elaborated by scholars working in North America and Europe (Lyman and O’Brien 2003; Shennan 2000). Americanist archaeologists and ethnologists noted that when the material culture record was described in a particular manner, cultural trait frequencies approximated normal or unimodal distributions. Kroeber (1919, 257), for example, revealed the “underlying pulsation in the width of civilized women’s skirts, which is symmetrical and extends in its up and down beat over a full century,” while Nelson (1916, 167) attributed the “normal frequency curve” exhibited by a pottery type across superposed excavation units to reflect a style that “came slowly into vogue, attained a maximum and began a grad-

ual decline” within a long-resident population. These expectations for the temporal distribution of transmitted (also called mimicked, borrowed, or diffused) traits were similarly applied to the spatial dimension of cultural transmission (e.g., Ford 1952).

Several recent archaeological studies have developed these culture historical generalizations into a more robust theoretical framework (e.g., Lipo et al. 1997; Teltser 1995; Tschauner 1994). This framework is based on generalizing evolutionary theory beyond its original biological purview, so that artifactual variation is *conceptually* similar to phenotypic variation and is a product of cultural transmission, distinct from biological transmission (Leonard and Jones 1987; O’Brien and Lyman 2002, *contra* Collard et al. 2007). Scholars working in the so-called evolutionary archaeology tradition have long focused on the problem of generating relevant descriptions of the archaeological record using classifications that define homologous and analogous similarities (e.g., Allen 1996; Cochrane

2002a; Lipo 2001; Meltzer 1981; O'Brien et al. 2002) and employing linked explanatory processes such as cultural transmission, drift, and selection for the differential persistence of artifact types.

Most research, however, using evolutionary theory to explain human behavior and material culture has not developed from this Americanist culture historical base. Instead, many anthropologists and archaeologists (e.g., Bettinger and Eerkens 1999; Kohler, VanBuskirk, and Ruscavage-Barz 2004; MacDonald 1998; McElreath, Boyd, and Richerson 2003; Smith and Winterhalder 1992; Soltis, Boyd, and Richerson 1995) pursuing evolutionary explanations have focused on the complex cultural transmission patterns predicted by studies derived from population genetic-based models (e.g., Boyd and Richerson 1985), behavioral ecology (e.g., Krebs and Davies 1993), and social learning frameworks. The empirical expectations for cultural trait distributions in particular scenarios are then used to explain portions of the behavioral and material culture records. Henrich (2004), for example, constructed a mathematical model to compare the distributions of complex and simple skills over time in a finite population of cultural transmitters. Applying this model to the archaeological and ethnohistorical records of Tasmania, he argued that the loss of complex technologies over time resulted from a sudden decrease in effective population size and the difficulty of transmitting complex skills (cf. Read 2006; Henrich 2006). Like Henrich's analysis, most contemporary use of cultural transmission is closely related to the seminal work of Boyd and Richerson (1985) and Cavalli-Sforza and Feldman (1981). While the explanatory frameworks used in this research tradition, known as dual inheritance theory (also gene-culture coevolution), do not share the same Americanist culture historical origins as much of evolutionary archaeology, both programs are used to explain archaeological variation as a result of cultural transmission and related evolutionary processes. Of course categorizing evolutionary approaches in archaeology as two hermetically separated traditions is somewhat an overstate-

ment as a few scholars have recently attempted to combine the two (e.g., Eerkens and Lipo 2005; Shennan 2003).

Here I explore some of the consequences of explaining archaeological variation using either dual inheritance theory or evolutionary archaeology. For instance, the dual inheritance framework is largely built to explain observable or potentially observable behavior, not the archaeological record. Thus, some dual inheritance observational units—for example, costly-punishment behavior—may not be unambiguously applicable to the archaeological record (cf. Dunnell 1995, 39–40). And for any scientific explanatory theory to be useful, relevant observational categories must be clearly applicable to the empirical record of interest (Willer and Willer 1973). This, of course, does not mean the architects of the dual inheritance framework have not done their work. The responsibility for constructing a dynamically and empirically sufficient theory to explain the archaeological record lies with those who try to explain it.

To explore the relationship between theory and the empirical record, the next section compares the explanatory framework and empirical evidence of two well-established evolutionary sciences: palaeontology and neontological evolutionary biology. This comparison parallels that between dual inheritance theory and the framework of evolutionary archaeology (see also Mesoudi, Whiten, and Laland 2006). The subsequent section suggests some of the principal elements of both dual inheritance and evolutionary archaeology approaches that should be necessary components of a scientific evolutionary framework built to explain the archaeological record. These ideas are demonstrated by applying the framework to the archaeological record of ceramic change in the south Pacific.

EVOLUTIONARY THEORY APPLIED TO THE "FOSSIL" AND BEHAVIORAL RECORDS

Grantham (2004) has recently compared palaeontology and neontological evolutionary biology (i.e., the evolutionary study of living

TABLE 8.1. *Comparison of the Fields of Neontological Evolutionary Biology and Evolutionary Paleobiology*

	NEONTOLOGICAL EVOLUTIONARY BIOLOGY	EVOLUTIONARY PALEOBIOLOGY
Focus of study	Living organisms	Fossil remains of organisms
Temporal perspective	Shorter term: $10^2 - 10^3$ years	Typically longer term: $10^3 - 10^7$ years
Theory	Models of natural selection and speciation, generally articulated in terms of population or quantitative genetics	Relies on broader neo-Darwinian theory; rarely uses population genetic theory. Some distinctively paleobiological theory (e.g., taphonomy)
Methods	Greater emphasis on experiments	Less emphasis on experiments
Data	Emphasizes genetic data and population structure	Extremely limited access to genetic data and population structure

NOTE: From Grantham (2004, 690).

organisms, hereafter evolutionary biology) in a way that highlights a set of similar, but not identical, contrasts between the dual inheritance and evolutionary archaeology frameworks. Grantham notes that both palaeontology and evolutionary biology are grounded in the theory of natural selection; practitioners in both are interested in explaining organic diversity; and they share a common technique, cladistics. Palaeontologists apply cladistics to the analysis of morphological characters, while those studying living populations can examine genetic characters in addition to morphologies. Grantham (2004, 690) compares palaeontology and evolutionary biology by noting focus of study (i.e., empirical record), temporal perspective, theoretical concepts, methods, and data (table 8.1).

Grantham does not compare the two disciplines by the classification units they use. Evolutionary biologists generally use a biological (i.e., reproductive) species concept (largely attributed to Mayr [see O'Brien and Lyman 2000, 200–207]) to place organisms into species groups. Palaeontologists, working with a different empirical record and not observing the reproductive behavior of organisms, must arrange organisms using different criteria, relying mostly on morphology and spatiotemporal distribution (Eldredge and Gould 1972; Gould and Eldredge 1977; Simpson 1943). Regardless of the differing theoretical ramifications of bio-

logical and palaeontological species concepts—punctuated equilibrium and the reality of species are two examples—O'Brien and Lyman (2000, 43) note a distinction of importance for classification issues: “What appears to work well for an ecologist, for example, whose specimens are living organisms, does not work particularly well for a paleobiologist, whose subject matter for the most part consists of preserved hard parts of long-dead organisms.” This distinction also pertains to evolutionary explanations of human cultural variation using either the behavioral or archaeological records.

We can compare the structure of dual inheritance explanations of human cultural variation to the framework of evolutionary archaeology using Grantham's system. Indeed, for several of Grantham's comparisons, we can simply change the column headings to dual inheritance theory and evolutionary archaeology (table 8.2). The focus of study or record that dual inheritance theory was originally built to explain is observations of human behavior (e.g., Boyd and Richerson 1985, chapter 3). For evolutionary archaeology, the empirical record to explain consists of artifacts and their temporal and spatial variation. This point bears further discussion.

The focus on artifacts does not mean evolutionary archaeologists think behavior is unimportant. On the contrary, the archaeological record captures variation in the *material results*

TABLE 8.2. *Comparison of Dual Inheritance Theory and Evolutionary Archaeology*

	DUAL INHERITANCE THEORY	EVOLUTIONARY ARCHAEOLOGY
Focus of study	Extant and modeled populations	Archaeological record
Temporal Perspective	Less than one day to tens of years	Hundreds to millions of years
Theory	Transmission and decision rules, population genetic theory	Transmission and selection models, neutral trait models
Methods	Ethnographic fieldwork, mathematical modeling	Seriation, cladistics, materials science/performance analyses, less emphasis on mathematical modeling
Data	Observations of behavior	Artifacts and the results of behavior
Observational units	Little emphasis on how to construct observational units	Large emphasis on how to construct observational units

NOTE: Categories from Grantham (2004, 690).

of behavior through time and space. And potential explanations using processes such as selection are evaluated by examining variation in these material results. Again, selection here is broadened from its restricted definition pertaining to organismal reproduction and refers to any differential replication of entities where replication is influenced by the relative advantage some entities may have over others in an adaptive context. For example, consider the increase of shell-tempered pottery in southeast Missouri from approximately 500–1400 CE. Feathers (2006) argues that this frequency change—that is, variation in the material results of behavior—is likely explained by selection as shell-tempered pottery performed better than sand-tempered pottery within the adaptive environment of the pottery makers. The basis for this performance claim lies in the measurable differences in strength properties, fracture toughness, and work-of-fracture across different shell-tempered and sand-tempered ceramic classes. A series of other measures (permeability, yield, deformation) also suggests that ceramic strength is the empirical property under selection. Finally, spatially and temporally variable changes in firing technology and subsistence practices likely led to different adaptive environments in which some shell-tempered potteries were advantageous relative to other pottery types.

Obviously, human behavior is inferred throughout this possible explanation. People worked clay into vessels with variable amounts and kinds of temper. They fired pots at different temperatures and over different lengths of time. They ate different proportions and types of “wild” foods and tended crops, cooking them in various ways. But archaeologists do not observe this historically contingent pot making, fire stoking, and food preparing. Instead, we determine the evolutionary processes that shaped the distribution of different behaviors in a population where those different behaviors are unambiguously linked to empirical results in the archaeological record: vessel tempering behavior that is parsed in our construction of ceramic classes, firing behavior evidenced in ceramic cores and experimental refiring measurements, subsistence behavior that is captured in human bone chemistry. These behavioral inferences rely on immanent (Lyman and O’Brien 1998) or universal properties and processes that link the archaeological record and human behavior. Sometimes our assumptions about universal processes and properties will be unhelpful or unsupportable, but these may often be classification or analytical errors. We may, for example, inaccurately describe firing behavior from sherd cores due to misclassification or unrecognized reactions between ceramic phases. Nevertheless, firing environment, and therefore

this aspect of human behavior, always influences certain herd characteristics.

Other differences between evolutionary archaeology and dual inheritance theory are noted in table 8.2. Temporal perspective is often markedly different in the two approaches. Methods, the procedures we employ to quantify our observations in meaningful ways, may be different in each kind of study, with greater emphasis on mathematical modeling in dual inheritance frameworks. Data are different, typically observations of behavior for dual inheritance theory and observations of the results of behavior or artifacts for evolutionary archaeology. And the construction of observational units is treated differently. In the evolutionary archaeology literature, much effort has been spent on the procedures for substantiating the ability of artifact classes, either newly constructed classes (e.g., O'Brien et al. 2002) or those used by culture historians (e.g., Lipo et al. 1997), to measure evolutionary relatedness. Classes might also be evaluated on their ability to track similarity and differences due to similar natural and social environments (e.g., Hurt and Rakita 2001). In contrast, how to construct and evaluate the ability of observational units to track either homologous or analogous similarity has received little attention in the dual inheritance literature. At least one likely reason for this is the relative ease of identifying homologous similarities, those arising from cultural transmission within related lineages, in ethnographic and experimental populations.

What are some ramifications of the theoretical differences between dual inheritance and evolutionary archaeology approaches suggested by table 8.2? Theory, laments Wilson (1998, 52), is "a word hobbled by multiple meanings . . . [and] in everyday context shot through with corrupting ambiguity." In the natural sciences, theory is a set of propositions that order the world of investigation built by a dialectic cycle of abstract reasoning and observation. Theory provides the rules by which we try to understand the world, the pertinent observational units, and the explanatory relationships between those units

(Dunnell 1982; Lewontin 1974; Willer and Willer 1973). Even with this simplified definition, some theoretical elements of dual inheritance and evolutionary archaeology approaches should be different as the approaches were built with different kinds of observable phenomena in mind. For example, dual inheritance theory postulates different transmission routes—vertical, horizontal, and oblique—and these different routes may partly explain the distribution of culturally transmitted variants in successive generations. Numerous empirical studies of human behavior use these different routes as explanatory concepts (Boyd and Richerson 1985, table 3.4). Very few (e.g., Henrich 2004; MacDonald 1998) archaeological studies use transmission route concepts in attempts to explain archaeological variation. One reason there are few uses of transmission route concepts in archaeological explanations is the difficulty of unambiguously relating archaeological observational units to transmission routes. This is not to say that transmission routes are unimportant in explanations of behavioral variation, simply that they are less easily applied in explanations of the archaeological record. Imagine a similar situation in palaeontology and evolutionary ecology. Biologists may explain increased reproductive success of particular males in a living population to be a result of rank in a dominance hierarchy (Emlen and Oring 1977). A dominance hierarchy model may not be viable for paleontologists studying the differential representation of morphological traits in extinct taxa, because mating behavior is not observable, and the time scale of interest is orders of magnitude different. This does not mean that in general dominance hierarchy models are missing some necessary component (i.e., dynamically insufficient) but simply that, these models, like all aspects of scientific theory, are built to explain a bounded portion of the empirical world.

The general applicability of transmission route concepts to the behavioral and archaeological records exemplifies one difference between dual inheritance and evolutionary archaeology approaches. Two additional important differences

include the prevalent use of decision rules in dual inheritance studies and the greater concern with classification issues in evolutionary archaeology.

Can decision rules be used to explain archaeological variation? Decision rules describe how different conditions influence the probability that cultural variants will be transmitted between individuals in population and include, for example, frequency-dependent transmission and guided variation (Boyd and Richerson 1985). The use of decision rules to explain the archaeological record includes a few studies that employ Neiman's (1995) neutral model as a baseline and explain variant frequencies that depart from neutral expectations as evidence for the workings of particular decision rules (e.g., Bentley and Shennan 2003; Kohler et al. 2004; Shennan and Wilkinson 2001). Another, less used approach in archaeology applies decision rule expectations directly to archaeological distributions without comparison to neutral null expectations. These studies seem to concentrate on what is often considered adaptive artifactual variation (e.g., Bettinger and Eerkens 1999; Henrich 2004).

Decision rules are sorting mechanisms and are conceptually similar to artificial selection in that the diversity of behaviors transmitted in a population is modified by human decisions, intentional or not. The problematic issue for archaeologists, however, is how to link decision rule expectations to distributional data generated through the creation and application of artifact classes. And when archaeological distributions match decision rule expectations, what are the explanatory alternatives, and how are these assessed? Bettinger and Eerkens (1999) provide an example of the archaeological use of decision rules. They demonstrated that various metric attributes of Rosegate-type projectile points in central Nevada are significantly correlated, while attributes of the same point type in eastern California are not. Bettinger and Eerkens hypothesize that attribute correlation in central Nevada Rosegate points is a result of individuals copying all the point attributes of successful models or indirectly biased transmission. They suggest the uncorrelated attributes in eastern California

Rosegate points are a result of individuals copying the points of successful models and then modifying some point attributes in a trial-and-error fashion. This is guided variation. As Bettinger and Eerkens (1999, 240) note, these hypotheses need further evaluation. One possible evaluative method involves experimental transmission studies (e.g., McElreath et al. 2005). Indeed, recent work by Mesoudi and O'Brien (2006) confirms that within an experimental population of university undergraduates, variation in attribute correlation across projectile points can be a product of indirect bias and guided variation.

Even with experimental work, evaluating decision-rule hypotheses applied to archaeological data will be difficult (although difficulty is certainly not a reason to forgo this work). Experimental transmission studies might initially target particular archaeological hypotheses for evaluation (as did Mesoudi and O'Brien 2008) and will require more complicated experiments when more complex decision-making rules are proposed, such as prestige-biased transmission (Henrich and Gil-White 2001) or rules that dictate transmission with individuals sharing similar ethnic markers (McElreath et al. 2003). In addition to experimental transmission analyses, research that evaluates the relative performance of artifacts in adaptive contexts may provide a methodological bridge between dual inheritance and evolutionary archaeology.

Along with differences in the use of transmission routes and decision rules, there are also differences between dual inheritance and evolutionary archaeology approaches in the use and construction of observational units. As mentioned at the beginning of this chapter, evolutionary archaeologists have a somewhat uncommon concern with constructing artifact classifications. The primary reason for continuous development and evaluation of artifact classifications is the requirement for any evolutionary study to describe the archaeological record in a fashion that identifies similarities resulting from transmission. Those who study and model living populations can analytically

define a transmitting population as the individuals under study. Allowing for variation in human perception (Eerkens 2000), observed variation is unambiguously interpreted as a partial product of transmission between individuals. Archaeologists, however, confront an empirical record comprising the results of behavior and often a record that preserves these results only on a corporate scale and over time spans much greater than living populations. Thus, a necessary initial question to ask in evolutionary analysis of the archaeological record is how to construct observational units that track cultural transmission. Any observational unit—ethnographic or emic pottery types, chemical compositional groups, attribute association types—may not track variation explicable via transmission. Increasingly, archaeologists and others have developed distributional and statistical expectations for artifact classes that track transmission (e.g., Lipo 2001; Neiman 1995; O'Brien et al. 2002; Pocklington 2006).

Lipo (2001), for example, used expectations for the distribution of selectively neutral traits in a population and random walk tests to evaluate the degree to which ceramic classes applied to Mississippi River valley assemblages captured neutral culturally transmitted variation. Lipo then used these classes to build frequency seriations of contemporaneous assemblages. Sets of successfully seriated assemblages demarcate the spatial location of a population defined by transmission and heritable continuity (see also Lipo et al. 1997).

O'Brien et al. (2002) used a form of occurrence seriation similar to a multistate transformation series analysis in cladistics to test the ability of their projectile point classes to measure transmission. Their seriations arrange projectile point classes in a series of equally parsimonious sequences (i.e., each with the same number of character state transformations) and indicate which projectile point class is likely the most ancestral of the group. Describing occurrence seriation, O'Brien et al. (2002, 141–142) argue that when the technique is properly applied and units are arranged so character

presence/absence is continuous and overlapping, “the result is strong supporting evidence that we are dealing with heritable continuity” (see O'Brien and Lyman 1999 for and expanded discussion of seriation).

These differences between the dual inheritance and evolutionary archaeology programs stem in part from the different empirical records that are their major focus of explanation. However, as both programs share the goal of explaining human cultural variation as a result of transmission, selection, innovation, and other evolutionary processes, some elements of each program should be compatible with both the archaeological and behavioral records. This would also be expected if we consider that dual inheritance theory and evolutionary archaeology can be differentiated as micro- and macroevolutionary studies, respectively (Mesoudi et al. 2006). The next section presents an example of how dual inheritance concepts and evolutionary archaeology may be combined using the archaeology of ceramic change in the southwest Pacific.

A COMBINED EVOLUTIONARY HYPOTHESIS FOR FIJIAN CERAMIC CHANGE

Ceramic types in the archipelagos of the southwest Pacific have often been linked to culturally distinct groups. Different kinds of ceramics, often identified through various surface treatments, have suggested new populations moving into an area or cultural change within a population over time. The Lapita ceramic series, for example, is generally interpreted as one marker of a culturally distinct population that colonized a large area of the southwest Pacific approximately 3,000–3,500 years ago (Kirch 1997). Unique ceramic changes in a number of archipelagos first inhabited by this population suggest later cultural differentiation (Spriggs 2004). Such explanations of ceramic variation in the Pacific are similar to the sociocultural interpretations of phases produced by Americanist culture historians (Cochrane 2005; Hunt 1986). In contrast, pottery variation in the Pacific has

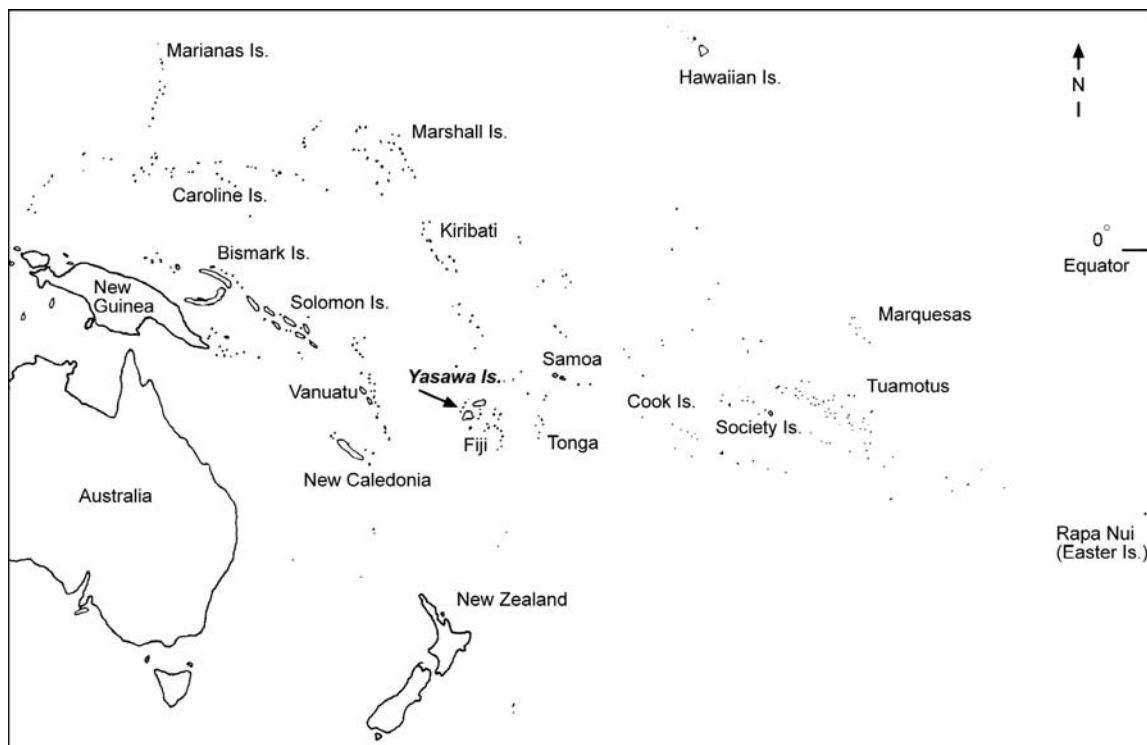


FIGURE 8.1 Map of the Pacific showing Fiji and the Yasawa Islands.

rarely been explained as a result of evolutionary processes as developed within a dual inheritance or evolutionary archaeology framework.

In the remainder of this chapter, I develop an evolutionary hypothesis to account for changes in the thickness of ceramic vessels over a 2,700-year period on Waya Island in the Yasawa Islands of western Fiji. Previous research in Fiji has concentrated on chronological and spatial variation in ceramic surface treatment and vessel forms, often interpreted in terms of intra- and interarchipelagic interaction in the region. The goal of the analysis here is to exemplify ways in which the strengths of evolutionary archaeology and dual inheritance approaches can be combined in a framework for archaeological explanation.

The Yasawa Islands of western Fiji (figure 8.1) comprise six main islands and several islets stretching some eighty kilometers in a straight line forty kilometers west of the main Fijian island of Viti Levu. The Yasawas were initially inhabited approximately 2,700 years ago, perhaps 300 years later than the first occupied areas of Fiji (Anderson and Clark 1999;

Cochrane 2004; Nunn et al. 2004). Yasawas Islands archaeological deposits contain abundant low-fired earthenware with a range of decorative and formal variation used to divide Fijian prehistory into periods (table 8.3). Pottery in the Yasawas and Fiji appears to have been produced at a household level as there is currently no evidence for large-scale manufacturing or functional integration of different production units.

Archaeological research in the Yasawa Islands has consistently been concerned with generating descriptions of the archaeological record with classification systems that track heritable continuity (Cochrane 2002b, 2004, 2008), a methodological focus of evolutionary archaeology as described earlier. Similarities in Yasawa Islands ceramics, when described using classes built from particular observations or modes, describe transmission patterns spanning the human occupation of the islands. The spatial and temporal characteristics of these transmission patterns have been generated through both cladistic and seriation analyses (Cochrane 2004).

TABLE 8.3. *Overview of Fijian Prehistory*

TIME PERIOD	PERIOD NAME	CERAMICS	SUBSISTENCE	SOCIAL ORGANIZATION	REFERENCES
3,000–2,500 years BP	Sigatoka	Lapita and plainwares	Generalized horticulture, marine resources	Colonizing populations	Anderson and Clark (1999); Birks (1973); Burley and Dickinson (2004); Kirch (1997)
2,500–1,000 years BP	Navatu	Paddle- impressed wares, plainwares	Increasing horticultural variation, marine resources	Population expansion, settlement shifts	Burley (2005); Clark (2000); Cochrane and Neff (2006)
1,000–200 years BP	Vuda	Plainwares, incised and appliqué wares	Agriculture, horticulture, marine resources	Aggregated settlements, defended habitations	Field (2004); Hunt (1987)
200 BP–present	Rā	Historic wares, appliqué wares	Agriculture, horticulture, marine resources	European contact, population collapse	Frost (1979)

NOTE: Minor variation in timing of periods not shown for simplicity; see Best (2002), Burley (2003), Clark (1999), and Green (1963).

Seriation analysis of the Yasawa Islands ceramic assemblages, described by various surface treatment classes, indicates the distribution of surface treatment classes over time and across the Yasawa Islands is likely a product of cultural transmission. Figure 8.2 depicts a seriation where surface modification class frequencies are monotonically distributed over assemblages from across the Yasawa Islands and from deposits dating to colonization up to the recent past. This seriation, however, does not conform perfectly to

the model as the distribution of two classes, Rectangular Paddle Impressing and Rectilinear Incision, are not monotonic and continuous. The other class distributions follow the seriation model within the 95 percent confidence intervals for estimating the frequency of classes. Finally, the assemblage from Y2-39 (8-1), is not described by multiple classes that *overlap* with other assemblages in the order.

Even though these Yasawa Islands assemblages do not conform in all respects to the

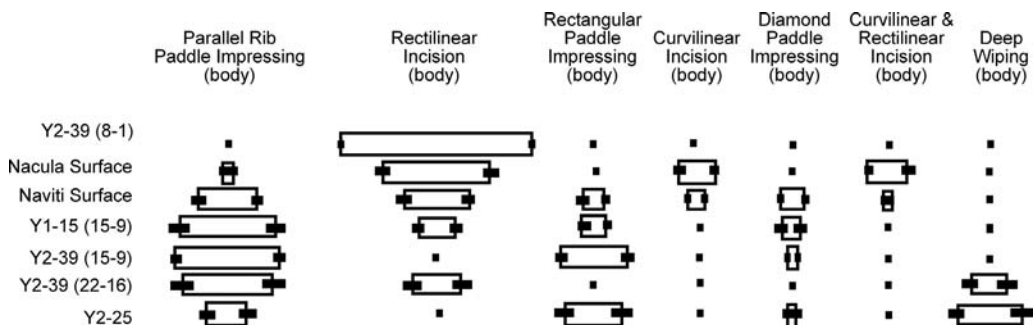
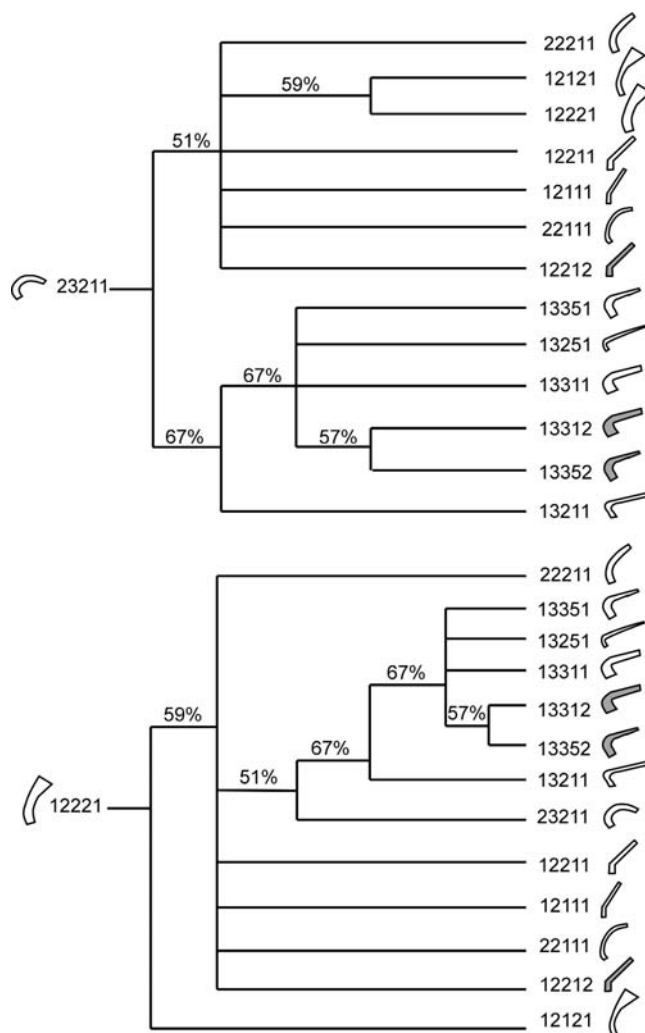


FIGURE 8.2 Seriation of seven Yasawa Islands ceramic body sherd assemblages. Assemblage names are cited at the left and class names as column heads. Open rectangles represent class frequency within a particular assemblage. Black bars denote error terms calculated at 95 percent confidence intervals, following Lipo (2001). See Cochrane (2004) for materials and methods.

FIGURE 8.3 Phylogenetic trees representing hypothesized relationships among fourteen Yasawa Islands ceramic rim classes, using two different outgroups. Class definition codes are shown next to each rim illustration. These 50 percent majority-rule consensus trees are generated from 1,974 equally parsimonious trees. Illustrations of classes (interior of vessel to left) convey characteristics of the class only and do not depict actual specimens. Shaded rims are tempered with terrigenous sands. See Cochrane (2004) for a full description of materials and methods.



frequency seriation model, it seems likely that with larger assemblages more conditions of the model will be met (Lipo 2001). If future research on assemblages representing the entire prehistory of the islands bears this out, then we can suggest that the Yasawa Islands were inhabited by a single population sharing traits through cultural transmission from colonization up to the recent past.

Phylogenetic transmission patterns were also explored in the Yasawa Islands assemblages with trees generated using maximum-parsimony methods in PAUP* 4.0 (Swofford 2002). The phylogenetic analyses were conducted on some of the same archaeological assemblages used in the seriation analysis, but for the phylogenetic analysis, only sherds described by a rim

classification were used. This classification was evaluated in the same manner presented in O'Brien et al. (2002). Several phylogenetic trees and their clades, or groups of related transmission lineages at several hierarchical levels, were generated and two are presented in figure 8.3. These phylogenetic trees of ceramic classes are constructed with different but equally applicable outgroups, and they share similar topologies each depicting a clade of recent ceramic classes (class defined beginning with 3) evolved from a common pool of ancestral variation approximately five hundred years ago (see Cochrane 2004 for full analysis).

With methods such as seriation and cladistics, along with evolutionary archaeology's

typical concern with artifact classification, we can define both Darwinian populations and transmission lineages within these populations. A logical next step is to develop hypotheses to account for spatial and temporal variation among populations (e.g., Lipo, Feathers, and Dunnell 2005) or among transmission lineages within populations, such as the origins of ceramic rim class clades (e.g., Cochrane and Neff 2006). In accounting for variation within and between populations, evolutionary archaeology and dual inheritance theory find close common interest.

A transmission lineage is an empirical distribution of an artifact class or classes where the distribution conforms to the expectations of heritable continuity (O'Brien and Lyman 2000). How might we explain the spatial, temporal, and class characteristics of a lineage relative to other lineages or clades? Consider, for example, a lineage defined by steatite vessel classes relative to other container technologies—say, pottery, sandstone, and basket classes all joined in a clade of related transmission lineages. The temporal and spatial distribution of the steatite class lineage might be explained by a relative advantage that these vessels exhibit compared with other container technologies (Truncer 2004). First, we should demonstrate that all of these container classes were present within a population of cultural transmitters. Second, both steatite vessel class frequencies and independent measures of relative advantage, such as those offered through material science experiments, would have to conform to a model of traits under selection—differential persistence related to relative advantage in a particular environment. This logic has been adopted by evolutionary archaeologists and others (e.g., Braun 1987; Feathers 1989; Hoard et al. 1995; O'Brien et al. 1994; Schiffer and Skibo 1987, 1997). In a similar sense, dual inheritance theory suggests that variation in the expression of a cultural trait in a lineage may be explained by cultural transmission and one or more decision rules. Different decision rules may produce different expected distributions of cultural trait variants, and most decision rules

are based on the assumption that variants differ in the potential biological adaptiveness they confer.

Dual inheritance theory and evolutionary archaeology differ, however, in their use of the concept selection. Selection in dual inheritance theory refers to the differential persistence of genes, natural selection *sensu stricto*, not the generalized meaning favored by evolutionary archaeology as the differential persistence of inherited variants in either the separate genetic or cultural transmission systems (Leonard and Jones 1987; Neff 2000; O'Brien and Lyman 2002). Thus, natural selection in dual inheritance theory shapes cultural trait distributions through the removal of models (people) from which naïve individuals might have learned cultural traits (Boyd and Richerson 1985, 174–175), although many dual inheritance models suggest natural selection plays little part as its effects are overwhelmed by the effects of learning.

How might decision rules as developed within dual inheritance theory and the generalized model of selection in evolutionary archaeology be used to explain variation within a lineage? To address this, I examined change in sherd thickness over time at the Qaranicagi cave site on Waya Island in the Yasawa Islands of western Fiji. Deposits at Qaranicagi cover the 2,700 years of human occupation in the Yasawas and pottery deposition at this site was fairly continuous (Cochrane 2002b). The site was used for a range of activities, including food processing and consumption, evidenced by midden deposits of fish, shellfish, mammal, and bird remains and multiple hearth features. Ceremonial burial activities also took place within the confines of the cave, and lithic tools and debitage indicate tool use and manufacture or retouch within the site (Cochrane 2004; Cochrane, Pietruszewsky, and Douglas 2004). Assessment of the heritability of vessel thickness at Qaranicagi has not been completed. For the moment, we must rely on the analyses of ceramic rim form and decoration that indicate variation in these cultural traits is a product of

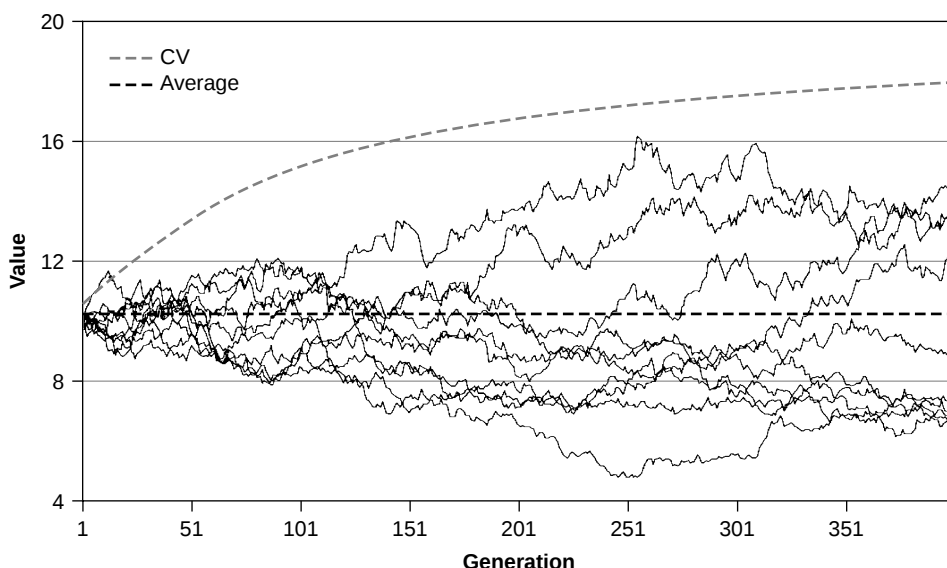


FIGURE 8.4 Eerkens and Lipo's (2005) figure 1 reproduced. Changes are shown in the value of a metric trait in ten lineages over four hundred transmission generations. The average value and the coefficient of variation of the trait in the ten lineages are also displayed.

transmission within one or more lineages in a population and assume that the thickness of these vessels was also a learned trait passed between individuals over the time span of the Qaranicagi ceramic sequence.

A first step in analyzing thickness variation here is to compare sherd thickness with expectations based on a null model. A stochastic null model has been developed in both the dual inheritance theory and evolutionary archaeology frameworks: unbiased transmission (Boyd and Richerson 1985) and the neutral model (Lipo 2001; Neiman 1995), respectively. These models propose that trait frequencies in a cultural generation are a product of prior frequencies, the rate of innovation, and effective population size, and trait frequencies are not affected by differential persistence due to relative advantage. Neutral model evaluations have previously been made using estimates of class diversity following Neiman (1995) and by comparing variant frequencies to power law distributions (e.g., Bentley, Hahn, and Shennan 2004; Bentley and Shennan 2003). Recently, Eerkens and Lipo (2005) formulated an unbiased transmission model where transmission of a continuous trait was simulated for ten related

lineages. They noted that if the only process influencing trait expression is copying error, then the value of the trait in each related lineage will diverge, the mean value across all lineages will stay roughly constant, and the coefficient of variation will increase over successive transmission generations (figure 8.4).

The Eerkens and Lipo model may explain sherd thickness data generated from the superposed pottery deposits at Qaranicagi. In comparison with their simulation, if vessel thickness is a cultural trait transmitted within a group of related lineages, and if variation in vessel thickness is explained solely by copying error—and not, for example, by a relative advantage conferred to vessels of different thickness—then the mean of thickness should remain the same within set confidence intervals over transmission generations. A plot of sherd thickness means across excavation levels, combined to reduce effects of sample size, indicates that mean sherd thickness does not remain the same (figure 8.5). Moreover, mean sherd thicknesses are significantly different ($F = 43.18$, $p < 0.0005$), although the outlier and extreme values may affect this ANOVA. These results suggest that variation in sherd thickness is not

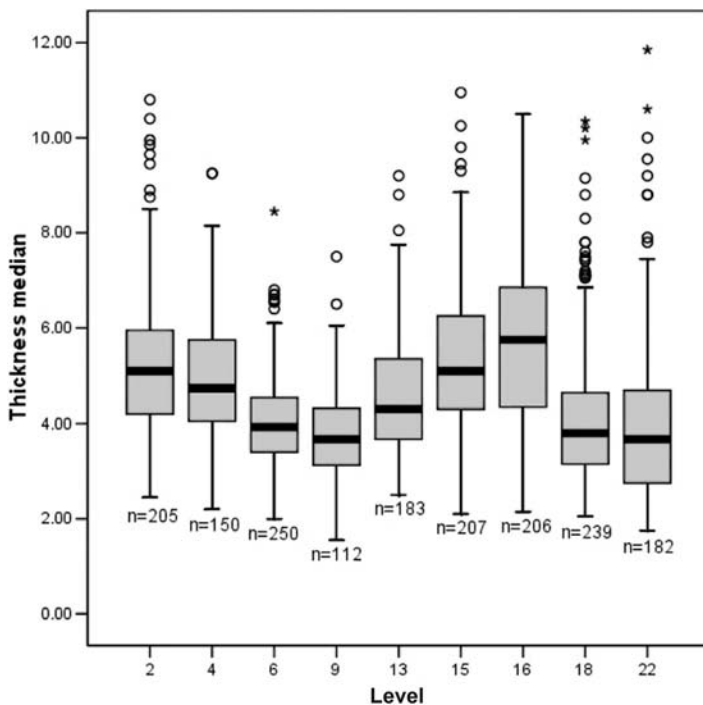


FIGURE 8.5 Box plot of mean body sherd thickness (in millimeters) per grouped excavation level at Qaranicagi (test unit 1), basal level to right. Circles are outliers; stars are extreme values. The deepest excavation levels, 17–23 (grouped into two units 18 and 22), contain material dated between 2300 and 2700 BP; levels 12–14 (grouped into a single unit 13) contain material dated between 920 and 1270 BP; and levels 2–6 contain materials dating from recent times to 550 BP. Age and depth of sediment are roughly correlated in a linear fashion. The same dates apply to figures 8.6 and 8.7. See Cochran (2002, 2004) for details of analysis.

explained by a null model of copying error. Analysis of the coefficient of variation of the sherd data supports this conclusion as well.

The coefficient of variation (CV) is one of several ways to characterize the amount of variation in a population measured by a variable. It is calculated by dividing the standard deviation of a set of measurements by the mean of the measurements and multiplying the quotient by 100. Like the mean, the CV of sherd thickness changes over time (figure 8.6). It decreases steadily from the earliest excavation levels at Qaranicagi until approximately level 6 (ca. 550 years ago); then the CV increases for the remainder of the sequence.

How might we apply the expectations of other decision rules to variation in the CV of body sherd thickness at Qaranicagi? Again, Eerkens and Lipo (2005) provide some null-model expectations as they simulated the effect of various forms of biased transmission on variance. They simulated conformist transmission where individuals acquiring traits may conform to an average value from the previous transmission generation, and prestige-biased transmis-

sion, where individuals may preferentially copy models from the previous generation based on the model's prestige. The strength of either conformity or prestige bias was altered for different simulation runs by changing the probability that individuals conform or choose a prestigious model. Eerkens and Lipo demonstrate that as the probability of either conformist or prestige-biased transmission increases, variance in the transmitted trait decreases.

Comparing the Eerkens and Lipo simulation results with the Fijian data suggests that the decrease in the CV of sherd thickness over the first 2,200 years of the Qaranicagi sequence might be explained by biased transmission, of either a conformist or prestige-based sort. To test the explanation that conformist or prestige-based transmission causes variation in CV, we can examine the coordination of trends in the CV of sherd thickness and thickness values themselves. Comparison of figures 8.6 and 8.7 shows that while CV was decreasing from initial occupation of Qaranicagi 2,700 years ago up to approximately 550 years ago, the trend in sherd thickness was to first increase and then

FIGURE 8.6 Plot of coefficient of variation (CV) of sherd thickness measures per grouped excavation level at Qaranicagi (test unit 1), basal excavation level to right.

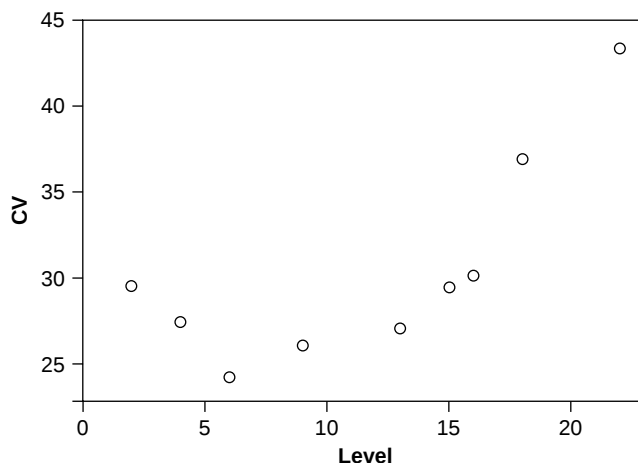
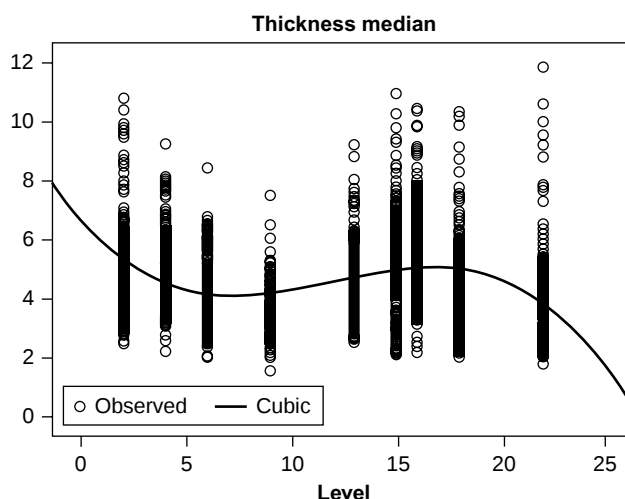


FIGURE 8.7 Plot of thickness measurements for sherds ($n = 1,734$) grouped by excavation level at Qaranicagi. Cubic regression line is the best fit to the data ($r^2 = 0.083$, $F = 52.38$, $p < 0.000$), although very little of the variation is explained.



continually decrease until about 550 years ago (although the regression in figure 8.7 explains very little of the variation). For the last 550 years, both the CV of sherd thickness and sherd thickness values increase.

Conformist transmission increases the frequency of adaptive cultural variants in a population (Boyd and Richerson 1985; Henrich and Boyd 1998). Therefore, at Qaranicagi, if vessel thickness variants are sorted by conformist transmission, then they should exhibit adaptive differences relative to a selective environment. Such adaptive differences have been evaluated by evolutionary archaeologists and others through material science analyses that attempt to quantify the differing performance of vari-

ants in particular contexts (e.g., Feathers 2006; Lyman, O'Brien, and Hayes 1998; O'Brien et al. 1994; Schiffer and Skibo 1987, 1997). Vessel thickness is one characteristic that influences the ability of pots to withstand the compressive and tensile forces on their exterior and interior surfaces when placed over a fire (other interrelated characteristics include porosity, paste grain, and temper grain size). Thin vessels, with higher thermal conductivity than thick vessels, are better able to resist the damaging effects of thermal stress because they have a smaller thermal gradient from exterior to interior. Thus, we might expect to find thinner vessels when and where prolonged and/or repeated cooking in pots is advantageous compared with other food

preparation technologies. For the Qaranicagi ceramics, the possible performance differences related to thermal stress between vessels of varying thickness could be assessed through thermal gradient analysis (see Lawrence and West 1982) of test specimens constructed to represent the range of thickness variants with their other ceramic characteristics (porosity, grain sizes).

Combining the adaptive logic of performance analyses and the conformist transmission hypothesis, we would expect a change in the selective environment that sorts variation in cooking technologies and vessel thickness at approximately 2,300 years ago when the trend changes from increasingly thick vessels to increasingly thin vessels occurs. Additionally, as the CV of sherd thickness is continually decreasing before and after the thickness trend change, it seems that the strength of selection potentially shaping sherd thickness is continually increasing during the first 2,200 years of occupation. Testing this expectation of the conformist transmission hypotheses might involve investigating dietary changes that require changes in cooking technology related to prolonged or repeated cooking over heat. Such dietary changes could be described through, for example, archaeofaunal, phytolith, and human bone isotope analysis. Protein and residue analyses of potsherds can provide direct evidence of changes in the kinds of foods consumed. Although some isotopic (Cochrane, Field, and Greenlee 2005) and faunal analyses (Hunt et al. 1999) have begun, additional work is necessary to evaluate the conformist transmission hypothesis in this manner.

As an alternative to conformist transmission, if prestige-based transmission explains the decrease in the CV of sherd thickness for the first 2,200 years at Qaranicagi, what corollary empirical expectations related to sherd thickness trends can we derive? Here, it seems most expectations would be plagued by causal equifinality given our empirical record of artifacts along with their temporal and spatial variation, and the behavioral record often used to generate empirical

expectations for prestige-biased transmission (Henrich and Gil-White 2001). While some may argue that the corollary expectations of dietary change in the conformist transmission hypothesis are also troubled by equifinality, it is material science analysis of performance differences that will provide an empirical link between ceramic thickness variation and the selective environment that sorts cooking technologies and subsistence variation. This is not to say that pot makers never engaged in preferential copying of cliques or particular models. Like the example in the previous section of a paleontologist struggling to use dominance hierarchy models to explain reproductive success, we can expect that some aspects of dual inheritance theory will not be applicable to the archaeological record.

Trends in sherd thickness might also be explained through hierarchical sorting or hitchhiking (Hurt et al. 2001; Vrba and Gould 1986). Hierarchical sorting occurs when an evolutionary process such as selection has shaped the differential representation of entities at a particular level in a hierarchy such that lower-level entities are also differentially represented. This process may explain the differential persistence of thickness variants at Qaranicagi as summarized by the trend in the CV of sherd thickness. For example, different vessel types (e.g., water storage, food storage, cooking, ceremony, and transportation vessels) may have different functional thickness parameters. If there is a reduction in the diversity of vessel types, perhaps as a result of selection removing vessel repertoires that are more costly in terms of time, knowledge, and materials to produce (Cochrane 2002b), then different sets of thickness parameters associated with vessel types may also be removed—this is hierarchical sorting. The trend toward lower CV of sherd thickness values during the first 2,200 years at Qaranicagi may be tracking the changing diversity of vessel types over time and the removal of vessel types with widely varying thickness parameters. Indeed, archaeologists have for some time noted a decrease in vessel type diversity beginning shortly after colonization of Fiji and the nearby archipelagos of Tonga

and Samoa (analyses summarized in Burley and Clark 2003). Additionally, unlike other areas of Fiji–West Polynesia where vessel type diversity decreases throughout prehistory, Burley (2005) has recently argued that at the Sigatoka Dunes site in western Fiji (the same general area as Qaranicagi), this trend of declining vessel type diversity stops approximately 1,600 years ago, and diversity increases as new vessel types begin to appear in the Sigatoka ceramic assemblages. Although vessel type diversity data for Qaranicagi are inconclusive on this point (Cochrane 2002b, 2004), the late increase in the CV of sherd thickness at Qaranicagi may also reflect the addition of vessel types that expand the thickness parameters employed by potters.

CONCLUSION

Explanation of the archaeological record can apply insights and models from dual inheritance theory constructed largely to explain observable behavior, but we are limited in our use of dual inheritance transmission models when the archaeological record is the focus of explanation. In the Qaranicagi ceramics example, a conformist transmission explanation can be evaluated by investigating the ceramic performance expectations of potentially adaptive traits and corollary expectations of archaeological patterning. A prestige-based transmission model, however, seems to have no unambiguous additional empirical expectations even though both models would produce similar patterns in the CV of ceramic traits.

The differences between the explanatory frameworks of paleontology and evolutionary biology are closely paralleled in evolutionary archaeology and dual inheritance frameworks. Evolutionary archaeology and dual inheritance theory are built primarily to explain different empirical records—the record of artifacts and the living record of behavior. An archaeological explanatory system cannot necessarily be built from only those processes that explain living systems; instead, it needs to be built in dynamically and empirically sufficient terms using

insights from both dual inheritance and evolutionary archaeology theory. Gould (1980) recognized a similar problem when paleontologists continued to apply microevolutionary processes to the fossil record.

Several years ago, Bettinger and Eerkens (1999, 239) suggested that “there is a general tendency for archaeologists to assume that differences in cultural transmission are unimportant. We suppose that reflects a common misconception that Darwinian forces are all obvious, strong, and life threatening.” Now an apt statement might read, “While archaeologists increasingly recognize the importance of cultural transmission, some concepts from dual inheritance theory built to explain a behavioral record may lack empirical sufficiency when dealing with the archaeological record.”

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NINE

Identifying Iron Production Lineages

A CASE STUDY IN NORTHWEST WALES

Michael F. Charlton

IRON PRODUCTION technology is inseparably linked to social, economic, and ecological changes of the last three millennia in the Old World and historic centuries in the New World. An evolutionary analysis of ironmaking behavior can add significant insight into these changes and serve as a platform for investigating theoretical problems related to the transmission of technological knowledge, innovation, industrial organization, and manufacturing strategies. From an archaeological perspective, this task must begin with the identification of technological traditions or lineages. Only in this way can we monitor the descent of ironmaking knowledge and its modifications across time and space.

Evolutionary archaeologists advocate a research strategy of constructing artifact lineages using homologous traits—those that share an inherited structure—and then explaining lineage morphology as a consequence of artifact–environment interaction. The methods currently available for constructing artifact lineages, including seriation and cladistics (O'Brien and Lyman 2000, 271–300; O'Brien, Darwent, and Lyman 2001), have been applied most success-

fully to formal attributes like shape and decoration on common archaeological finds (pot sherds, stone tools, fibulae, etc.). These kinds of artifacts are the result of product engineering and design. Homologous and analogous similarity is more readily distinguished across a range of formal traits in finished artifacts because of relatively low levels of morphological constraint present in their stylistic features. However, whether a particular trait is stylistic or functional (*sensu* Dunnell 1978) must always remain hypothetical and subject to empirical testing (e.g., Allen 1996; Meltzer 1981).

Identifying lineages of process engineering, especially high-temperature metallurgical processes, presents rather different methodological challenges. Constraints imposed by system requirements and available resources often restrict the available forms of residual artifacts to a tightly bounded set of possibilities. Such can be the case regardless of the levels of variation present in the technology. Variation must therefore be studied at the scale of artifact microstructure or chemistry, requiring new methods of unit construction. Then there is the problem of arranging these classes into an evolutionary

chronicle, one from which it is possible to infer homologous similarity between units. This is a problem because there is no obvious reason why the same engineering solution to a technological problem cannot be realized multiple times, even in the same lineage.

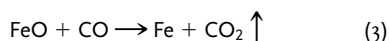
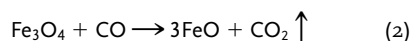
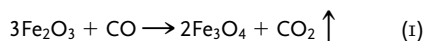
This chapter presents one method for resolving these problems as understood in the context of bloomery iron smelting technology. The most abundant and most informative artifact of this process is slag—a once-molten silicate mixture whose chemistry is derived from ore, fuel, and furnace construction materials, as well as furnace operation. The chemistry of bloomery slag thus contains an abstract record of the smelting recipe used to produce iron. An outline of bloomery smelting technology is provided, highlighting possible sources of variation in slag chemistry. Taking technological constraints of bloomery systems into consideration, a model is derived from evolutionary theory for building iron production lineages. The method is then empirically evaluated with materials from three archaeological bloomery sites in northwest Wales: Crawcwellt West (350 BCE–50 CE), Bryn y Castell (50 BCE–200 CE), and Llwyn Du (1357–1450 CE).

BLOOMERY TECHNOLOGY

Bloomery iron smelting may be defined as the intentional reduction of minerals rich in iron oxide to solid iron metal by thermochemical means. Nonmetallic ore constituents like silica (SiO_2) and alumina (Al_2O_3) are removed as a liquid slag, while more volatile components are driven off as a gas. Successful reduction occurs across a narrow range of atmospheric conditions that are further limited by technological and resource-delimited constraints. This requires numerous trade-offs in performance parameters.

All reactions take place inside a specially constructed furnace, heated by burning charcoal or some other carbon-rich fuel with continuous supplies of air. Some of the resulting heat is used to generate the reducing agent (carbon

monoxide gas) through the reaction of carbon dioxide gas with unburned fuel. Carbon monoxide then reduces the iron oxide in the ore according to the following sequence of reactions:



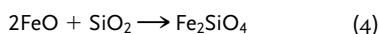
Temperatures inside typical bloomery furnaces are raised to 1,100–1,400°C in the combustion zone (Bachmann 1982, 10; Craddock 1995, 199; Tylecote 1986, 129) and become progressively cooler toward the top of the shaft or mouth of the furnace. Because of the relatively high oxygen content of the combustion zone, no reduction is likely to take place here. Reducing conditions are much greater just above the combustion zone in what is usually termed the reduction zone. The morphology, location, and distinctiveness of different furnace zones are functions of furnace design, operation, and natural resources. The length of time that iron minerals remain in each zone (residence time) will also affect the nature of bloom formation.

Pure metallic iron remains solid at temperatures below 1,540°C. Thus, one of the hallmark characteristics of bloomery smelting is the solid-state reduction of iron oxide into metal. Small particles of metallic iron begin to sinter together, gradually forming an entangled network called a bloom. In experiments and ethnographic reconstructions, the bloom tends to form on the furnace wall just below the tuyère or blowhole (but see Sauder and Williams 2002 for a different result and set of interpretations). This process is almost always aided by the production of a fluid slag.

Iron ores never consist of pure iron minerals but, rather, include varying quantities of unwanted gangue minerals, usually rich in silica. Impurities not removed through mechanical processing must be removed thermochemically as gas (escaping into the atmosphere) and slag. Once formed, a low-viscosity liquid slag serves

as a medium that facilitates the transport and collection of solid iron particles into a bloom. Slag also acts as a heat reservoir, conserving energy needed to drive endothermic reactions, and protects the bloom and iron particles from oxidation near the combustion zone.

The melting point of pure silica is 1,723°C. This is much higher than typical furnace operating temperatures, so some means of reducing the melting point of gangue minerals must be used instead. Fluxes are substances that react with other materials in order to form a new phase with a lower melting temperature. Iron oxide is a flux for silica and upon reaction forms the new phase fayalite:



This phase has the twin advantages of melting in the same temperature range (around 1,200°C) that bloomery furnaces typically operate and having a low viscosity relative to temperature. The obvious disadvantage is that much of the desired iron is used up in making a fluid slag. Other oxides, particularly manganese oxide (MnO) and lime (CaO), can also serve as fluxing agents. Their use provides the additional benefit of substituting for iron in fayalite, thereby elevating the yield of metal. Sufficient quantities of lime can promote the formation of pyroxene, making even more iron available for the bloom. Most iron ores, however, are self-fluxing and do not strictly require further additives to ensure a fluid slag (Craddock 1995, 244).

Silica, manganese oxide, and lime are, of course, not the only ore contaminants. Others of consequence include alumina, phosphorus oxide (P₂O₅), and arsenic (As). Alumina is removed in the slag, but phosphorus and arsenic partition into the metal and atmosphere as well as the slag. Melting furnace walls, tuyères, and small amounts of fuel ash will also be dissolved in the slag, affecting its viscosity and final chemical and phase compositions (Craddock 1995, 146).

A low-viscosity slag is desirable for two reasons. First, it is much easier for iron particles to

congeal if its medium is free-flowing. Second, the more fluid a slag is, the greater its separation is from the bloom. The better the separation is, the higher the net metallic yield will be. Slag viscosity is largely controlled by temperature and chemistry. A temperature between 1,200 and 1,300°C is generally sufficient to create a low-viscosity fayalitic slag without melting too much of the furnace lining. Melting of the lining results in significant increases of silica and alumina in the slag, both of which increase the viscosity of slag (Bachmann 1982, 19).

Ironworking requires the procurement of a number of raw materials and their subsequent processing. These can include ore, wood, clays, and various other items necessary for furnace construction and operation. The kinds of materials and the manner by which they are acquired, processed, and used will inevitably influence the properties of the bloom and serve as the principal sources of chemical variation in slag. Some are highly constrained by the availability of resources and create strong geographic patterning. Others allow for significant cultural variation in terms of both style and function. The most important variables are internal furnace design, ores, fuels, and furnace operation.

Furnace construction and operation coupled with the choice of resources and their methods of preparation constitute both the recipe and ingredients of a smelt and are reflected in the chemistry of blooms and bloomery slag. These relationships are complex and not always well defined. Even when controlling for the effects of geological variability, there is no way to perfectly infer a smelting recipe from slag chemistry. Gross approximations can be made, however, by comparison of slag with associated ores and clays as well as through experimentation. This is not especially important for constructing technological lineages of bloomery smelting. It only matters that the variation in slag chemistry is structured, at least in part, by processes of cultural transmission and that these transmission pathways can be identified.

THEORY AND METHOD

The construction of cultural lineages serves as the cornerstone for exploring the evolution of ideas, technological or otherwise. Lineages are probably best perceived as maps of transmission pathways, highlighting relevant episodes of innovation and change (O'Hara 1993). Mapping these idea pathways is primarily a problem of inferring transmission from patterns of variation distributed across the space–time continuum at a given scale.

Diachronic variation is observable at three scales of an evolving system: ontogenetic, tokogenetic, and phylogenetic (O'Hara 1993, 237–239). Ontogenetic variation consists of the genetically/culturally programmed changes an entity goes through during its growth and development or construction. Tokogenetic variation is the result of differential information transfer and interaction between members of a single population. Tokogeny is modeled as complex interacting networks of individuals and is a reflection of microevolutionary processes. Phylogenetic variation is a reflection of population or higher-level descent patterns characterized by branching diversification. While information transfer between units (reticulation) is common at the tokogenetic scale, it is deemed absent or insignificant at the phylogenetic scale. Transmission pathways, selection, and constraint can be modeled at any of these scales, though archaeology typically only involves tokogenetic- and phylogenetic-level analyses. The model presented here is intended to track transmission in ironworking systems at the level of a single interacting population.

Archaeology has long possessed a tool for monitoring the structure of population interaction. Seriation, at its heart, is a stochastic model of cultural interaction and trait transmission (Lipo et al. 1997, 310). Variation is divided into classes distributed over single segments of the space–time continuum. Transmission is inferred when multiple classes overlap with one another across the continuum. As Neiman's (1995) computer simulations clearly demonstrate, this is precisely the pattern created by

unbiased transmission coupled with innovation. Seriation requires the use of “historical types”—those artifact types and classes that have singular continuous distributions across space-time (O'Brien and Lyman 2000, 284). Often this requirement has been worked out on the basis of experience and trial and error.

Seriation-like models, especially percentage-stratigraphy (see Lyman, Wolverton, and O'Brien 1998, 242–244), have previously been used to examine diachronic patterns of slag variation (e.g., Charlton 2002; Koucky and Steinberg 1982). However, the systematics for building appropriate units to measure cultural transmission from slag chemistry or other attributes is problematic. It is still unclear whether an arbitrarily defined slag class can truly represent a single distribution in space-time and behave like a historical type. Similar problems are found in palaeobiology (e.g., Reymont 1985, 187–189; Saunders and Swan 1984, 195), where it is noted that even while species morphology is inherited and displays a stochastic distribution in space-time, the actual location of a specimen in morphospace may be more a function of local constraints or adaptive convergence. A partial solution to this problem is to use an independent measure of time such as stratigraphic superpositioning. Transmission can still be inferred if (1) classes overlap with one another; (2) their distributions are semicontinuous (i.e., occupying segments rather than points through time); and (3) when class distributions repeat, they overlap with a series of phenetically related classes.

Principal component analysis (PCA) provides a means of representing multiple continuous quantitative attributes, many of which may be transmitted through social learning. Evolutionary biologists have recognized this with regard to the evolution of species morphology, suggesting that it “form[s] a natural coordinate system for the description of phenotypic evolution” (Maynard Smith et al. 1985, 273; see also Foote 1992, 1993, 1994, 1999; Reymont 1985; Saunders and Swan 1984). With slight

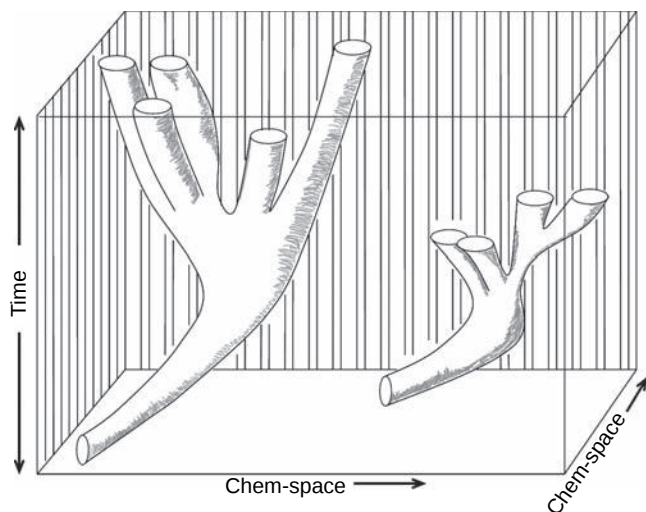


FIGURE 9.1 Evolving technological systems within a multidimensional design space. (Adapted from Clarke 1968, 147, figures 20[c] and 20[d].)

modification, a PCA approach similar to those of biologists should be amenable to tracking heritable chemical variation in iron slag.

The proposed method begins by ensuring that the slag sample is functionally homologous and not patterned by constraint. A PCA is then carried out on the sample as a whole. Each principal component axis is treated as an attribute and is evenly partitioned into a set of equivalent attribute states. The scores for each specimen are calculated, and a paradigmatic classification is formed from the intersection of the newly formed attribute states. In practice, this is unlikely to require the use of any more than the first two or three principal component axes. The amount of variation to be included in each class is dependent on sample size and the total range of variation exhibited by the slag sample. Each cell is a locally defined theoretical class appropriately constructed for monitoring stochastic patterns resulting from transmission (O'Brien and Lyman 2000, 190–191). When graphed over time, such classes should be characterized by overlapping contiguous distributions if they are related by descent. Interrupted distributions are only permissible where sample size is recognizably poor or where a closely related adjacent class had been occupied in the previous time-step. This procedure makes it possible to approximate the theoretical distribution of an

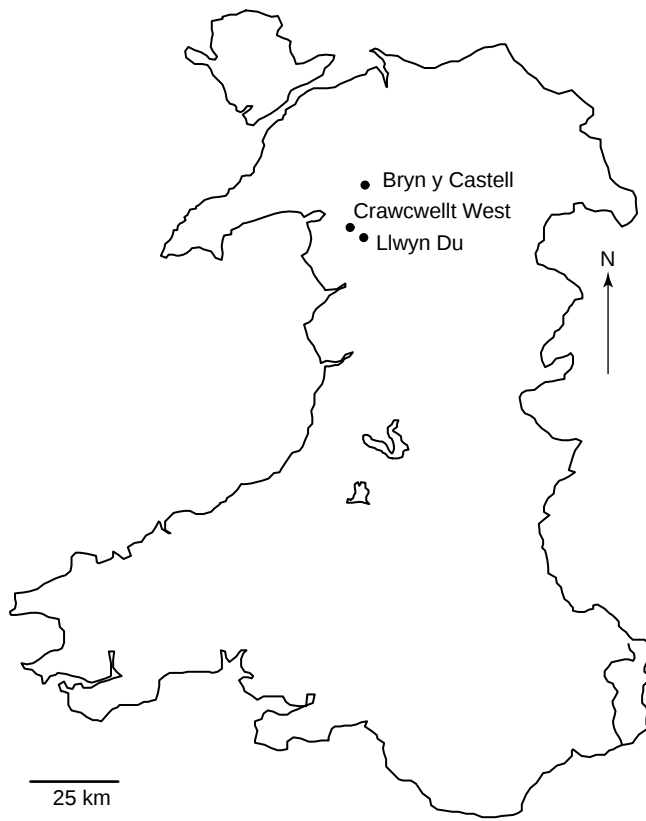
evolving slag system shown in figure 9.1. Functional consequences of changing smelting recipes may be monitored by comparing the relative positions of individual points and data swarms with the loading vectors of the original variables.

The importance of using some kind of classification system cannot be overemphasized. Even though variation within an evolving population is expected to be continuously distributed, sampling error and measurement procedures force the data into discontinuous points. Some tolerance limit has to be assigned in order to assess continuity or discontinuity over time. Such limits can be defined by using confidence intervals or density estimation, both of which require additional assumptions about data structure. A paradigmatic classification lacks these assumptions and is therefore more appropriate (at least at present) for identifying lineages.

RESULTS AND DISCUSSION

Following the procedure outlined here, lineage construction was attempted for Crawcwellt West, Bryn y Castell, and Llwyn Du (see map, figure 9.2). Each site occupies a unique portion of the temporal dimension and its occupants faced very different socioeconomic pressures.

FIGURE 9.2 Map of Wales showing the location of iron production sites.



Crawcwellt West (350 BCE–50 CE) is a large upland settlement situated entirely in the pre-Roman Iron Age (Crew 1989, 1995, 1998). This was a time when the importance of iron as a material was growing, though demand remained relatively low. Four structures at Crawcwellt West contain remnants of bloomery furnaces as well as remnant slag, ore, and clay. Each context can only be roughly dated, but they seem to suggest three phases of smelting activity (J5 → J1/A → H). Iron production was carried out on a relatively small scale over a long period of time resulting in 6.5 tons of slag. Most of the furnaces were of a low-shaft nontapping variety. However, the latest furnace had been clearly designed to promote slag tapping, which suggests that production intensity was increasing over time.

Bryn y Castell (50 BCE–200 CE) is a small hill fort with evidence for primary iron produc-

tion in three areas, two inside the walls of the hill fort and one at an external building labeled site A. Furnace design is very similar to that at Crawcwellt West though production was smaller in scale, resulting in a total of 1.2 tons of slag. The earliest smelting activity took place at the hill fort and dates (somewhat imprecisely) from the first century BCE (Crew 1984, 98). Slag from site A dates from the early first century CE and is contemporaneous with the latest smelting activity at the hill fort. This again suggests efforts to increase overall production toward the end of the prehistoric period. However, all activity ceased during the Roman occupation of northwest Wales (ca. 70 CE). Production resumed at site A soon after the local reduction in military presence around 150 and continued into the middle of the third century (Crew 1984, 1995). Phases are here defined as Hill fort → S → R → Q; where S, R, and Q

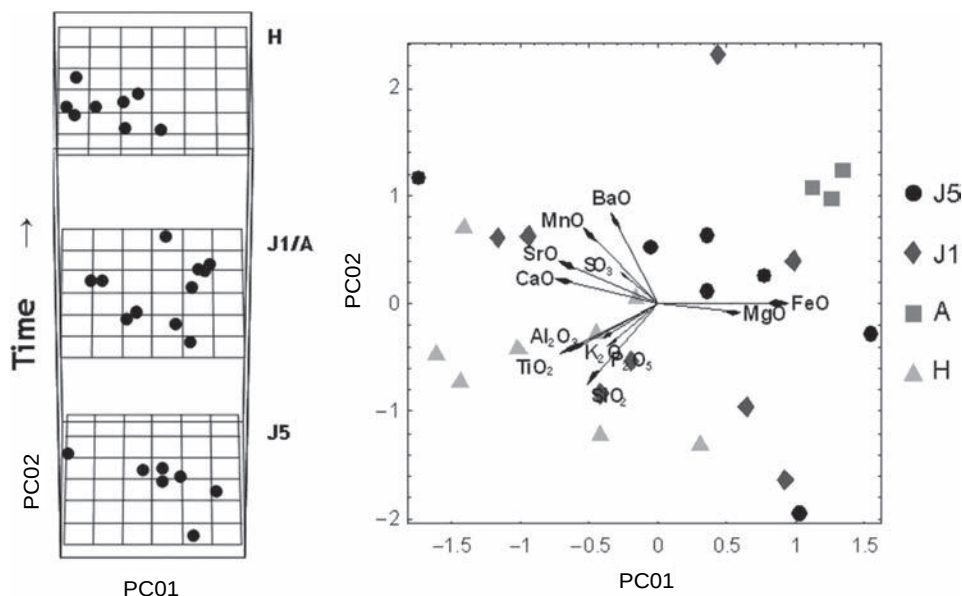


FIGURE 9.3 Hypothetical lineage for Crawcwell West (350 BCE–50 CE). The lineage remains relatively stable for the first two phases, then shifts to a high-manganese recipe in the third component. Phase H is dated to approximately 50 BCE, a time closely corresponding with Julius Caesar's conquest of Gaul and invasion of Britain.

are levels of the site A slag dump. Interestingly, the scale of production at Bryn y Castell seems to be lower at this time than in the pre-Roman Iron Age even though the demand for iron was generally higher during the Romano-British period.

Llwyn Du (Crew and Crew 2001) is one of several bloomeries in the northwest to start production during the turbulent years of the late fourteenth century, a time when both the demand and price of iron were extremely high. Iron production at Llwyn Du had a very different character from that of the prehistoric sites. Furnaces were larger, with thicker walls, slag was tapped, and production was on a relatively massive scale. There is also much greater use of high-manganese ores, with most slag specimens containing much more manganese oxide than those analyzed from Crawcwell West or Bryn y Castell. Production was carried out for an estimated fifty years and resulted in the accumulation of more than 250 tons of slag. This work seems to have been carried out in two major phases, though these can be subdivided

into several more. Five phases are used here (A → B1–B2 → B3 → C1 → C2).

PCAs were conducted on slag samples collected from each site using twelve technologically relevant oxides measured by X-ray fluorescence spectrometry (MgO, Al₂O₃, SiO₂, P₂O₅, SO₃, K₂O, CaO, TiO₂, MnO, FeO, SrO, and BaO). Specimen scores were then classified according to the procedure described earlier using the first two principal component axes. Representations of these lineages are shown in figures 9.3, 9.4, and 9.5.

A dynamic lineage can be inferred for Crawcwell West (figure 9.3) despite the fact that corrosion imposed a steep limitation on sample size. The one major directional change in the lineage is the gradual reduction of FeO in slag over time. This suggests that the ironmaking process was becoming increasingly efficient. This change appears to originate in phase J1/A, where the increased variation in slag chemistry hints at greater exploration of chemical possibility. Problems of equifinality prevent any attempt to explain the timing of this

exploration. A change in the selective regime could have prompted a short-lived increase in experimentation, but it is equally possible that new variants were added slowly over a long period and then obscured by time averaging. Lacking additional evidence, the changes in slag chemistry at Bryn y Castell west are best characterized as gradual and constant. Further work must be carried out to give more than intuitive strength to this argument.

The lineage hypothesized for Bryn y Castell (figure 9.4) shows remarkable stability. Once again, the sample size was heavily constrained by corrosion problems. Variation in slag chemistry seems to increase for the level Q sample, but this could be the result of sampling error. The only significant pattern of variation is the presence of a high-manganese group of slags derived from the hillfort, best observed in plots of the first and third PC axes. The high-manganese group is associated with the earliest bloomery activities at the hill fort but is not present in later phases. Assuming that the sample is not too strongly biased, three explanations for the disappearance of the high-manganese group seem reasonable. First, the earliest ironmaster(s) at Bryn y Castell may have failed to transmit the recipe to apprentices. Without transmission, there is little chance for particular variants to be produced by later generations unless a new history of innovation leads to a similar technological solution. Second, the high-manganese recipe may have promoted the production of steely blooms. Steel, though possessing superior strength and hardenability properties, is not easy to smith. If phosphoric iron—also possessing superior strength and hardenability properties—could be produced (and there are high-phosphorus ores at Bryn y Castell), then perhaps this somewhat less efficient recipe out-competed the high-manganese recipe. Third, some of the ores at Bryn y Castell are high in arsenic, which may have produced a bloom with properties that outperformed those of the high-manganese recipe. Arsenic hardens iron but also makes it extremely brittle in high con-

centrations. But arsenic does tend to concentrate on forging surfaces through a process of selective oxidation and can be advantageous for creating a clean welding surface as well as banded structures in finished artifacts. Further experiments with similar bog ore varieties may help assess these possibilities.

The Llwyn Du lineage (figure 9.5), despite its relatively short duration, is exceptionally dynamic and displays three observable trends. The first two are linked to the branching evolution beginning in phase B3. The slag chemistries appear to be divergent specializations that have evolved from a more generic ancestor. The slags associated with the right-hand branch exhibit chemistries that are more depleted of FeO than their predecessors. Slags associated with the left-hand branch have chemistries with higher concentrations of FeO. This pattern implies the production of two varieties of iron, probably steel and a relatively pure bloomery iron.

The third trend, observed on the third principal component axis, involves the gradual movement of both recipe branches toward chemistries with reduced concentrations of fuel-ash related oxides (CaO, MgO, and SrO) relative to both clay-related oxides (SiO₂, Al₂O₃, and TiO₂) and manganese-rich ore. There are several potential explanations for this pattern. One is that smelters were gradually relying on less fuel to make suitably reducing conditions; another is that the wood varieties for charcoal were slowly being replaced by one that produced higher amounts of CO₂ relative to ash. Recent examination of the palaeobotanical record provides evidence of woodland management for the time period in question (Tim Mighall, personal communication, 2005). While pollarding may have taken place, there are also changes in the ratio of oak and birch species within the nearby forests. Changes are also expected to have occurred in the age of wood being used to make fuel. A final possibility is that oak bark was removed by colliers in later phases for sale to other industries such as tanning.

A detailed program of materials analysis, experimentation, and historical research is

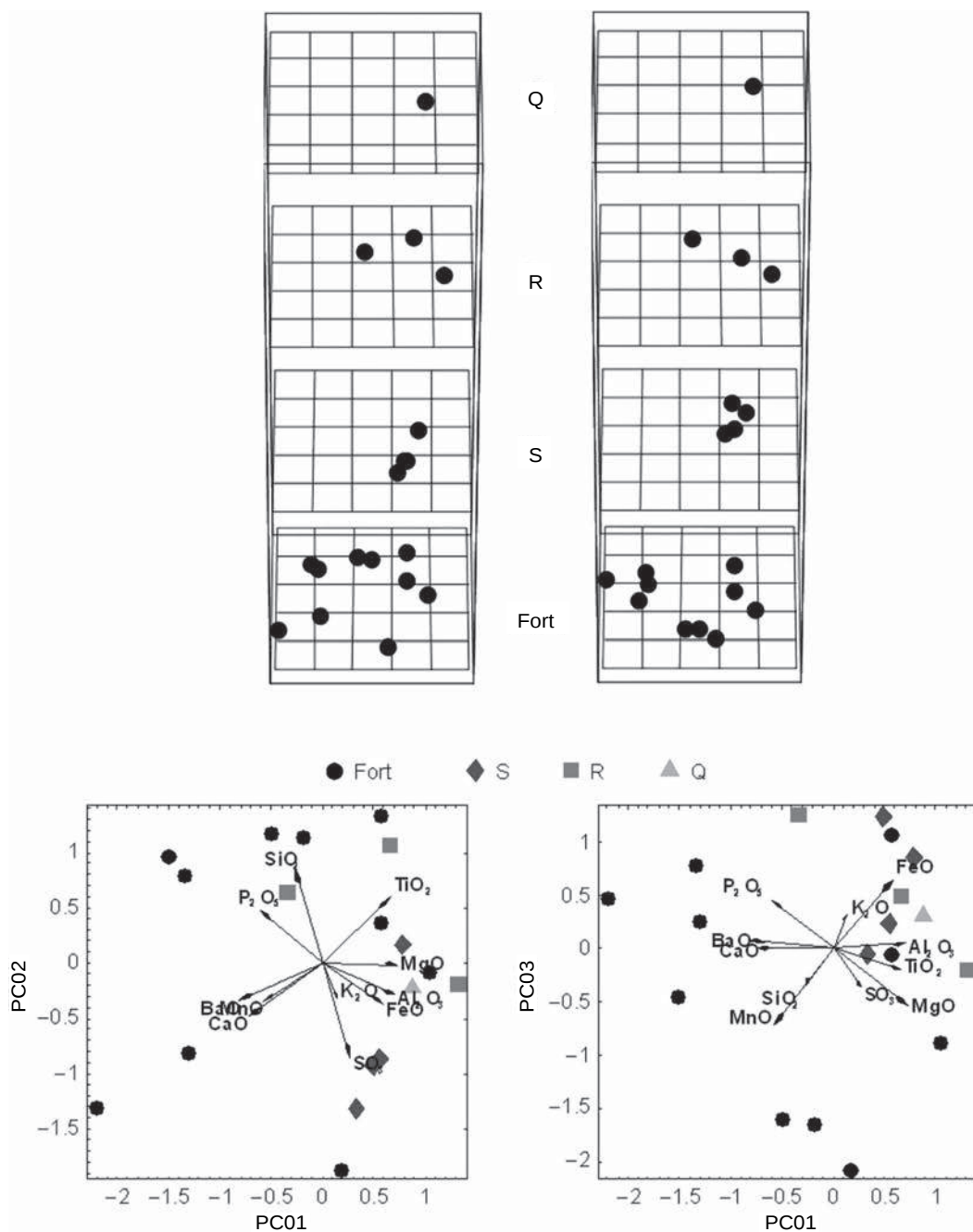


FIGURE 9.4 Hypothetical lineage for Bryn y Castell (50 BCE–200 CE). The history of smelting at Bryn y Castell is relatively uneventful. The earliest phase contains two recipes; one yielding a slag with higher manganese concentrations relative to the other. The high-manganese recipe was not replicated in later phases and the low-manganese recipe undergoes now identifiable changes.

required to test the character of Llwyn Du's bloomery products, fuel sources, and economic situation. As the chronology for Llwyn Du becomes more refined, it may prove possible to

link the archaeologically observed innovations with historically documented socioeconomic changes in the late fourteenth and early fifteenth centuries.

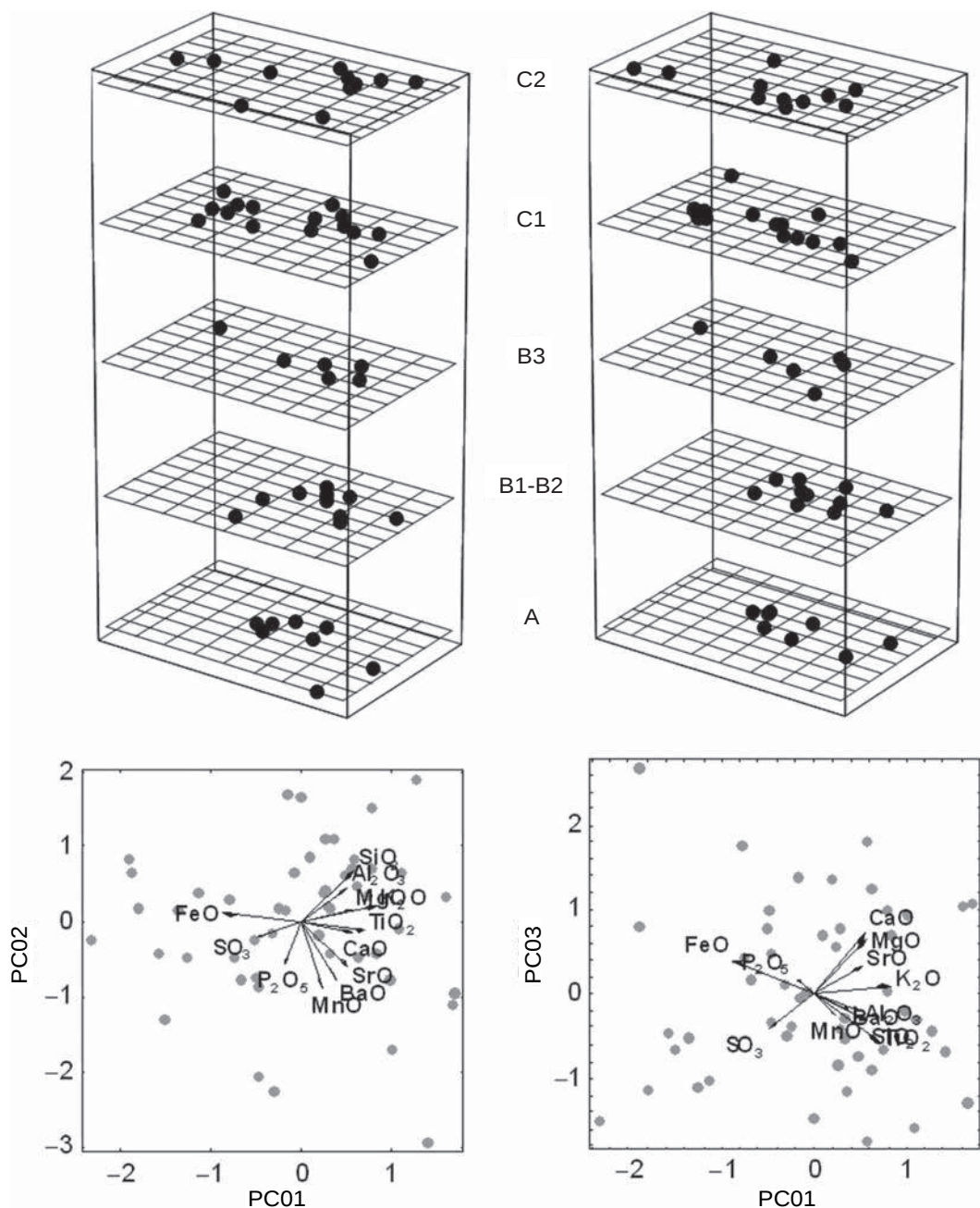


FIGURE 9.5 Hypothetical lineage for Llwyn Du (1357–1450 CE). The lineage is stable during the first three phases, then evolves a new chemical group through components C1 and C2. This may be the result of innovative behavior for the purpose of yielding a specialized bloom product, possibly steel. This figure shows the values for principal components 2 and 3, as well as 1 and 2.

CONCLUSIONS

While problems related to sample availability and corrosion reduce the empirical impact of this project, results suggest that it is possible to

construct iron production lineages from slag chemistry following the approach outlined in this chapter. The occurrence stratigraphy method suggested here is not wholly satisfying,

and future work will have to address the problem in terms of overlapping distribution fields and similarity in distribution shapes and orientations in a multidimensional space. However, the lineages constructed here can already begin to be explained in terms of changes in the social environment and provide a number of interesting avenues to explore through engineering, experimental, and historical analysis.

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Testing Evolutionary Hypotheses

Quantitative Analysis of Macroevolutionary Patterning in Technological Evolution

BICYCLE DESIGN FROM 1800 TO 2000

Mark W. Lake and Jay Venti

A RECURRING pattern in biological evolution is that increases in diversity (adaptive radiation) proceed by early diversification at higher taxonomic levels, followed by later diversification at lower taxonomic levels. Kauffman (1995, 205–206) has argued that this macroevolutionary pattern results from the increased cost of exploring distant locations in design space as evolution proceeds and is the expected outcome of any process of adaptive evolution irrespective of substrate. Indeed, he asserts that the development of the bicycle is a good example of a human design history that matches the pattern of adaptive radiation very closely (Kauffman 1995, 207). Van Nierop, Blankendaal, and Overbeeke's (1997) analysis of the development of the bicycle suggests that Kauffman's claim may be correct, although they were not specifically concerned with how bicycle design space was searched.

In this chapter, we develop a methodology that allows us to quantitatively evaluate Kauffman's claim. We follow Lyman and O'Brien (2000, 47–53) in making use of clade diversity statistics (Gould et al. 1977) to examine

the exploration of technological design space. However, unlike Lyman and O'Brien, we build an explicit hierarchical taxonomy of designs in order to investigate design diversity across different taxonomic levels.

ADAPTIVE RADIATION AND THE EVOLUTIONARY SEARCH OF DESIGN SPACE

The relative rates of speciation and extinction have varied in the course of biological evolution. When they are approximately equal at any given taxonomic level, there is little net gain or loss in diversity; but when speciation rates exceed extinction rates, the diversity of life increases. The latter phenomenon is known as an adaptive radiation, and it is usually associated with the colonization of an empty ecological space. As Ridley (2004, 644) notes, “adaptive radiations can occur at all taxonomic levels and on all geographical scales.” For example, the so-called Cambrian explosion produced many new phyla (the second-highest taxonomic level) across much of the Earth's surface (Gould 1989), while

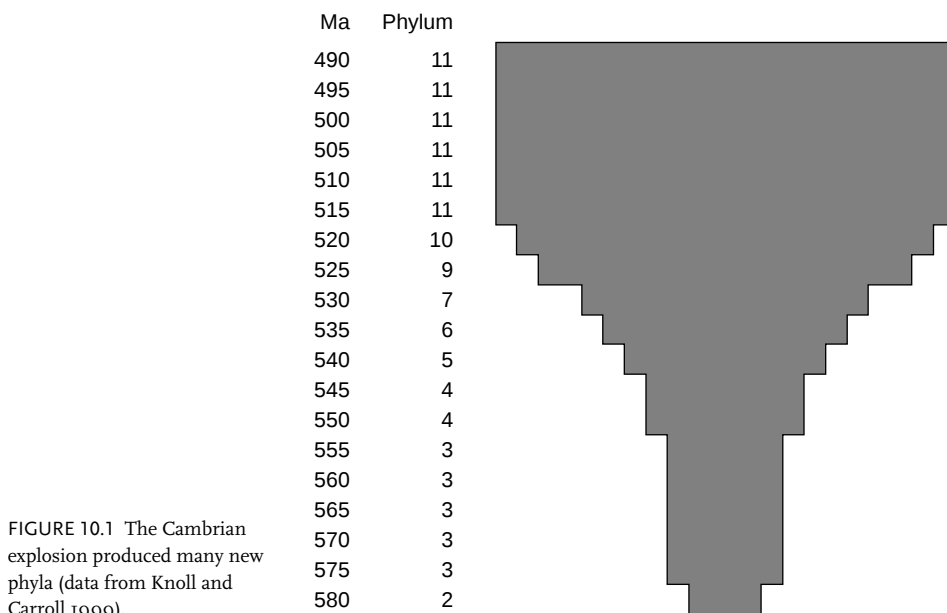


FIGURE 10.1 The Cambrian explosion produced many new phyla (data from Knoll and Carroll 1999).

in contrast, Darwin famously documented an adaptive radiation of finches that produced new genera, species, and subspecies (the lowest taxonomic levels) in the restricted area of the Galápagos Islands (Begon, Harper, and Townsend 1990, 19).

Irrespective of scale, adaptive radiation typically follows a pattern characterized by rapid evolutionary diversification into a broad set of higher taxonomic classes followed by “filling in” at lower taxonomic levels. Thus, for instance, families diverge relatively soon after the appearance of the orders to which they belong; and, in turn, genera diverge soon after the appearance of their families (Kauffman 1995, 200). This pattern of early high-level diversification later followed by lower-level diversification appears to be quite robust: even in the event of mass extinctions, evolution tends to produce new lower-level taxa within the surviving higher taxa, but rarely new higher level taxa. For example, starting about 550 million years ago, the Cambrian “explosion” first established all the major animal body plans—and hence phyla—that have ever existed (figure 10.1) and subsequently produced a further increase in diversity at the lower taxonomic levels of class, order, family, and so

on (Gould 1989). A massive decrease in the diversity of life occurred during the Permian extinctions about 200 million years ago. Although there is some debate about whether any phyla became extinct (see Lewin 1988 *contra* Knoll and Carroll 1999), it does appear that the subsequent rebound in diversity occurred at lower taxonomic levels within existing phyla rather than in the creation of new phyla (Erwin, Valentine, and Sepkoski 1987).

Evolutionary biologists often explain the pattern of adaptive radiation in terms of the filling of the “ecological barrel” (Gould et al. 1977, 38–39). The basic idea is that a relatively empty ecological space offers the greatest opportunity for the evolution of new forms of life, but as that space fills up, increasing competition reduces the probability of further diversification. It is important, however, to be aware of exactly what is—and what is not—being explained. Gould et al. (1977) invoke the barrel filling theory to explain early diversification but not specifically early diversification at higher taxonomic levels. In fact, Gould himself is careful to distinguish these two different phenomena, preferring the term *diversity* to refer to numbers of species and the term *disparity* to refer to numbers of

“anatomical designs for life” (Gould 1989, 49). Thus, diversification at low taxonomic levels produces an increase in diversity but little change in disparity, whereas diversification at higher taxonomic levels will also produce greater disparity. It is not immediately apparent that empty ecological spaces offer the greatest potential for the evolution of widely divergent forms of life; indeed, one could equally well propose that radical new forms of life would be most likely to succeed precisely because they avoid competition in congested spaces. Erwin et al. (1987, 1185) argue that the rapid increase in diversity displayed at the family level during the Cambrian explosion “is best interpreted as a consequence of the invasion of relatively empty adaptive zones by higher level taxa; the families were exploiting open opportunities within adaptive spaces to which higher-level taxa had achieved access.” While this invocation of the barrel filling theory clearly acknowledges that diversification initially occurred at higher taxonomic levels, it nevertheless does nothing to explain that particular fact.

Kauffman (1993, 1995) builds on the work of Gould et al., Erwin et al., and others in two important ways. First, he attempts to explain why early diversification occurs specifically at higher taxonomic levels; second, he attempts to investigate whether with this pattern is a general feature of evolution by natural selection, irrespective of substrate. To this end, he models evolution by natural selection as a search algorithm that seeks maxima in a correlated fitness landscape. The latter can be conceived as a multidimensional space describing all possible designs, each location being associated with a fitness. Kauffman’s model can be tuned to alter the correlation between the fitness of adjacent locations: a high degree of correlation produces a “smooth” landscape in which adjacent locations share similar fitness values, while a low degree of correlation produces a “rugged” landscape in which adjacent locations may have quite different fitness values (Kauffman 1993, 40–45). On a rugged landscape, simultaneous mutations effect a long-jump across design

space to a location whose fitness may be very different (better or worse), whereas single mutations effect a much shorter jump to a location whose fitness is likely to be closer to that at the origin. Kauffman finds that the chance of finding fitter variants by long-jump adaptation rapidly declines as evolution proceeds (71–74). This in turn leads him to propose that there are “three natural time scales” (74) to adaptation: an early phase in which evolution occurs by long jump to distant locations in design space, a middle phase in which further evolution occurs by short jumps that effect a kind of “hill climbing” to the fittest variants within smaller regions of design space, and a late phase of relative stasis awaiting increasingly improbable long jumps to more distant locations.

As archaeologists interested in cultural (and particularly technological) evolution, we are attracted to Kauffman’s model by its substrate neutrality and its explicit treatment of how design space is searched. Kauffman (1995, 179) argues that both biological and technological evolution occur on moderately rugged landscapes because both involve finding compromise solutions in the face of conflicting constraints. He goes on to suggest that the three-phase sequence of adaptation observed in his substrate neutral model of evolution by natural selection mirrors very closely the macroevolutionary patterns observed in both biological and technological evolution: specifically, in the Cambrian explosion (Kauffman 1993, 76) and in the design history of the bicycle (Kauffman 1995, 202). In the case of the Cambrian explosion, Kauffman proposes that the initial efficacy of long-jump adaptation led to evolution alighting on or near fitness maxima so distant from one another in design space that the resulting life forms fall within different high-level taxa. However, it rapidly became more difficult to locate distant fitter maxima, so evolution increasingly proceeded by hill climbing in the immediate vicinity of already occupied locations in design space, resulting in new life forms that fall within existing higher-level taxa but represent

new lower-level taxa. Kauffman suggests that the same explanation is applicable to the design history of the bicycle, which saw early diversification followed by standardization on a limited number of basic designs.

BICYCLE EVOLUTION

Although there were various attempts to construct a viable human powered carriage from the late seventeenth century onward, the forerunner of the modern bicycle is generally considered to be Baron Karl von Drais's *Laufmaschine* (running machine), patented in 1818 and more commonly called a "draisine" or "velocipede" (Herlihy 2004, 15–27). Constructed largely of wood, it comprised little more than a saddle slung between two spoked wheels. The initial name "running machine" was apt, since it had no mechanical drive and was propelled by the rider pushing his or her feet against the ground. Despite early enthusiasm, which included organized races and a London coach maker's proposal of a woman-specific model (Herlihy 2004, 37–38), the draisine never established a lasting market and became largely obsolete within a matter of years.

Over the next fifty years, various attempts were made to improve on the draisine by adding some kind of mechanical drive. These designs had either three or four wheels and introduced a wide range of drive systems, including a pre-wound spring, foot-operated treadle drive, hand-operated levers, and hand-operated rotary cranks (Herlihy 2004, 53–66). None made a huge impact until the introduction of the first pedal-operated velocipede in the late 1860s. Often considered the first true bicycle, the "boneshaker," which was probably invented by Pierre Lallement in 1862, was being produced in the thousands by 1867 (van Nierop et al. 1997, 260). Although the frame and wheels bear some resemblance to the draisine, the boneshaker incorporated pedals directly connected to the front wheel by cranks. This was not, however, the only means of propulsion used in boneshakers; in the late 1860s, Thomas

McCall built bicycles in which foot-operated treadles were connected to the rear wheel by means of rods (Herlihy 2004, 66–71). Rapid improvements to the boneshaker included the introduction of metal frames, wire wheels, and solid rubber tires.

In the 1870s, the boneshaker was largely replaced by the faster "high wheeler," on which the rider sat atop a very large front wheel of forty or more inches diameter. Although the high wheeler was more comfortable than the boneshaker, it was both more dangerous, because the rider would be thrown over the handlebars from a considerable height in the event of striking an obstacle, and also more difficult to mount (Herlihy 2004, 167).

From the late 1870s throughout the 1880s, there were numerous attempts to marry the speed of the high wheeler with greater safety. These included tricycles with large indirectly driven rear wheels, bicycles in which the large driving wheel was placed behind a smaller front wheel, "dwarf" high wheelers in which drive through a slightly smaller diameter front wheel was geared, and various designs that greatly reduced the size of both wheels and employed a geared chain drive to the rear wheel (Herlihy 2004, 200–251). By the early 1890s, the latter had become by far the most popular design and already resembled the modern bicycle: a so-called diamond frame with two equal-size wheels, the front steerable and the rear driven via a chain from cranks mounted below and forward of the saddle. This basic configuration has remained dominant for over a hundred years, despite the sporadic appearance of new designs such as the recumbent bicycle (although an early recumbent design dates from the height of the bicycle boom in the late 1890s; Herlihy 2004, 288).

What this necessarily concise history of bicycle design demonstrates is that the modern bicycle is not the result of a simple unilinear progression from the draisine (see also Pinch and Bijker 1990). Rather, it is one branch of a radiation in which many but not all other branches became extinct (see figure 10.2). It is

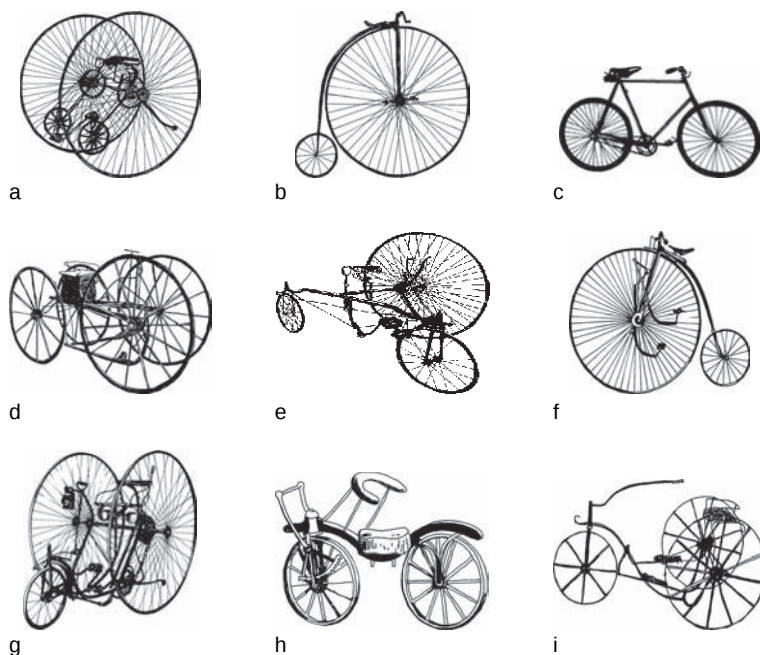


FIGURE 10.2 The diversity of early bicycle designs: (a) Otto dicycle, 1881; (b) Rudge ordinary bicycle, 1884; (c) Osmond safety bicycle, 1896; (d) Saywer's treadle-driven quadracycle, circa 1840; (e) Starley's Coventry Rotary Tricycle, circa 1878; (f) Singer Xtraordinary bicycle, 1878; (g) Starley Royal Salvo tricycle, 1880; (h) Gompertz's hand-cranked draisine, 1821; (i) treadle-driven bicycle, circa 1850. Sources: a, b, c, f, g, and i are redrawn from Caunter (1955), plates I, IV, V, VI, and X, by permission of Her Majesty's Stationery Office; d and e are redrawn by permission of Canada Science and Technology Museum; h is redrawn from *Polytechnisches Journal* (June 1821).

this observation that led Kauffman to suggest that the design history of the bicycle provides a good example of the similarity between technological and biological evolution in terms of how they search design space. Indeed, Kauffman's claim is that they are not just similar but fundamentally the same (Kauffman 1995, 203).

Van Nierop et al. (1997) were inspired by Kauffman's claims to undertake a largely qualitative investigation of bicycle design history. They constructed a fitness landscape that depicts the changing fitness of different basic designs over time, where the fitness is given by the relative popularity of those designs (256). As can be seen from figure 10.3, this clearly demonstrates (despite its truncation at 1900) a waxing and waning of bicycle diversity that does indeed look very much like an adaptive radiation. Van Nierop et al. do not, however, pursue this specific point

any further: they neither attempt a quantitative assessment of diversity per se, nor do they explicitly discuss how bicycle design space was searched. Instead, their primary interest lies in an engagement with Kauffman's wider framework for understanding dynamic systems; they seek to "clarify the following statement: that the patterns of co-evolving dynamic ecosystems, such as the bicycle–society system, show periods of stability, progressive complication, transitions with critical fluctuations to new states, and evolve to the edge of chaos to be maximally adaptive" (254). We are open to that possibility, but our ambition for this chapter is to develop a quantitative method by which we might empirically demonstrate whether changing diversity in the course of bicycle design history really is like that seen in biological adaptive radiation.

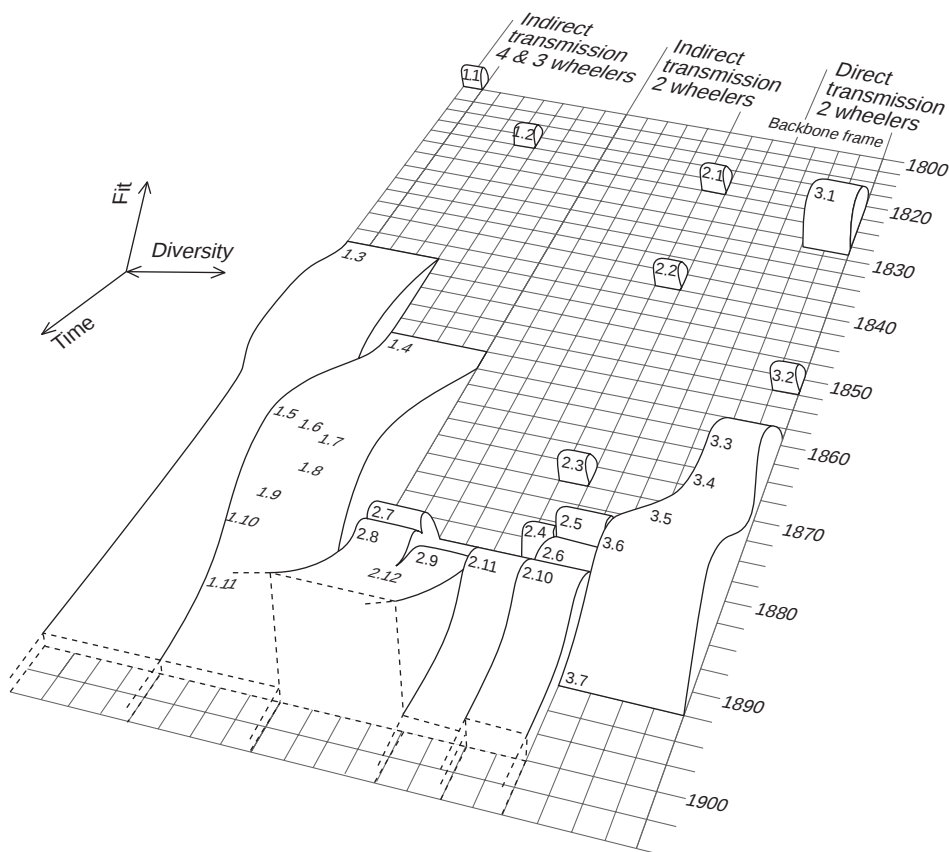


FIGURE 10.3 Van Nierop et al.'s model of changing bicycle design fitness (reproduced from van Nierop et al. 1997, figure 3, by permission of Oxford University Press and the authors).

AIMS, ASSUMPTIONS, AND METHOD

Our principal question is whether the history of bicycle design exhibits rapid diversification at higher taxonomic levels followed later by extinctions and/or diversification at lower levels. If this is indeed the case, then it would appear to support Kauffman's claim that technological evolution (at least in the case of some technologies) searches design space in the same way that biological evolution searches design space. Under these circumstances, it might be appropriate to talk of bicycle "evolution," but it is important to recognize that this does not require any assumption about exactly how such evolution occurs. Our question can be addressed without knowing whether bicycle designs can be ordered into monophyletic lineages or whether the degree of reticulation is so great as

to render that impossible (see O'Brien and Lyman 2003, 104–105 for a useful discussion of reticulation in culture). Our only assumption is that bicycle design as a whole constitutes a monophyletic lineage, which simply means that we ignore the possible import of design elements from other technologies. Note also that, unlike Van Nierop et al., we are concerned only with the diversity of design, not the fitness of individual designs. For our purposes, it makes no difference whether a particular design of bicycle was built just once or mass produced in the thousands (except insofar as that may impact our knowledge of the design). Given these assumptions, three main tasks are involved in answering our principal question: the first is to map bicycle design space by constructing a taxonomy of bicycle designs; the second is to

populate these taxonomic units according to the dates of the first and last known occurrences of specific designs; the third is to investigate the changing diversity of extant taxa.

BICYCLE DESIGN TAXONOMY

It is not immediately obvious how one should go about constructing a bicycle taxonomy. Van Nierop et al. (1997, figure 3) divide “bicycles” into three- and four-wheelers with indirect transmission, two-wheelers with indirect transmission, and two-wheelers with direct transmission. They also make a further cross-cutting distinction between two-wheelers with and without a “backbone.”

For our purposes, there are two problems with this scheme: the first is that it captures only a few dimensions of bicycle design space; and the second is that it is essentially flat, so it does not permit investigation of what happens at different taxonomic levels. Lyman and O’Brien’s (2000) investigation of how the design space occupied by portable radios was explored between 1920 and 1955 is no more helpful with regard to the second problem. They measured the changing diversity of radio design by assuming that the number of designs is correlated with the number of manufacturers (55) rather than by attempting to explicitly map radio design space by constructing a taxonomy of radio designs.

We have chosen to build a phenetic, aggregative hierarchical classification system similar in principle to that devised by Linnaeus for the classification of biological organisms. The advantage of such a system for our purposes is twofold. First, a phenetic system (one based on observed similarities and differences of form rather than relations of descent—see O’Brien and Lyman 2003, 31–34, for an introduction) is not dependent on a particular mode of evolutionary character transmission and so does not require us to make any assumptions about whether bicycle designs can be organized into monophyletic lineages. Of course, a phenetic classification may align with a phylogenetic classification, as indeed the Linnaean system

does to a considerable degree (Ridley 2004, 473); but whether a phylogenetic classification of bicycles is possible and, if so, whether it aligns with the taxonomy described later are questions that we are pursuing elsewhere. Second, an aggregative hierarchical classification system (see Valentine and May 1996, 26–29, for the properties of an aggregative hierarchy) allows us to analyze the changing occupancy of taxa across arbitrary levels, which is necessary to permit investigation of whether bicycle design space was initially explored by diversification across higher-level taxa. One further point to note is that a phenetic hierarchical system is not restricted to any particular kind of trait: in principle, it should be possible to construct taxonomies based on bicycle morphology, technology (mechanical coupling, materials used, etc.), or, for example, social context of use. Again, this is an issue that we intend to address elsewhere.

The specific taxonomy used in this chapter classifies bicycles according to their morphological and technological attributes—for example, the number of wheels, the type of transmission, which wheel is the drive wheel, and so on (see table 10.1 for the complete list). The hierarchical ordering (i.e., the level at which a particular attribute is considered) is based on Wimsatt’s (1986) notion of “generative entrenchment.” The basic idea is that mutations occurring early in development cause many downstream changes and so are relatively unlikely to produce viable organisms, whereas mutations occurring progressively later in development cause progressively fewer downstream changes and so are more likely to produce viable organisms (Schank and Wimsatt 1987, 37–38). Consequently, aspects of an organism that are laid down early in development are said to have high generative entrenchment because they are less likely to be altered in the course of evolution. Kauffman (1993, 77) argues that postextinction increases in diversity occur at lower taxonomic levels because it is precisely the developmentally early and thus highly entrenched attributes of organisms that are used to differentiate them at higher taxonomic levels.

TABLE 10.1. *Generatively Entrenched Bicycle Classification System*

ORDER	FEATURE CATEGORY	FEATURE TYPE	CODE
1	Number of wheels	Four wheels	C
		Three wheels	B
		Two wheels	A
2	Wheel configuration	Two front and one back	TO
		One front and two back	OT
		Asymmetrical	AY
		In-line	IL
		Parallel	PL
		Diagonal	DG
3	Drive technique	Nonmechanical	N
		Hand-operated lever	H
		Foot-operated pedals on crank	P
		Foot-operated treadle	T
4	Drive transmission type	Direct	D
		Indirect	I
5	Drive geometry type	Front drive	F
		Rear drive	R
		Side drive	S
6	Transmission linkage type	Gear and chain	G
		Gear and shaft	X
		Lever and crank	L
		Lever and gear	V
		Direct crank	Z

Although expounded in a biological context, Wimsatt's model is equally applicable to any process that explores a design space in such a manner that early "choices" constrain subsequent possibilities. This is clearly true of bicycles. For example, a bicycle whose pedals and cranks are not directly coupled to the driving wheel may have either a chain- or shaft-based transmission, whereas a bicycle whose pedals and cranks are directly coupled to the driving wheel can have neither kind of transmission. Thus, we argue that the choice between direct and indirect drive is more generatively entrenched than the choice of transmission method, which is why we make the former distinction at a higher taxonomic level than the latter. Similar logic has been applied to the hierarchical placement of all other attributes listed in table 10.1.

The second stage of our analysis populates the taxonomic units according to the dates of the first and last known occurrences of specific bicycle designs. In other words, we classify each bicycle design into the leaf taxa depicted in figure 10.4 and record the first and last known dates of production of that design. Note that since we are not explicitly concerned with design fitness, we do not record how many individual manufacturers' designs fall within a given taxon or the quantities in which they were produced. For our purposes, we simply need to know the duration when a given taxon was occupied by one or more bicycles. The data used to populate the taxonomy comprised published images of bicycles collected from the following sources: Bijker 1995; Caunter 1955; Dodge 1996; Herlihy 2004; van Nierop et al. 1997.

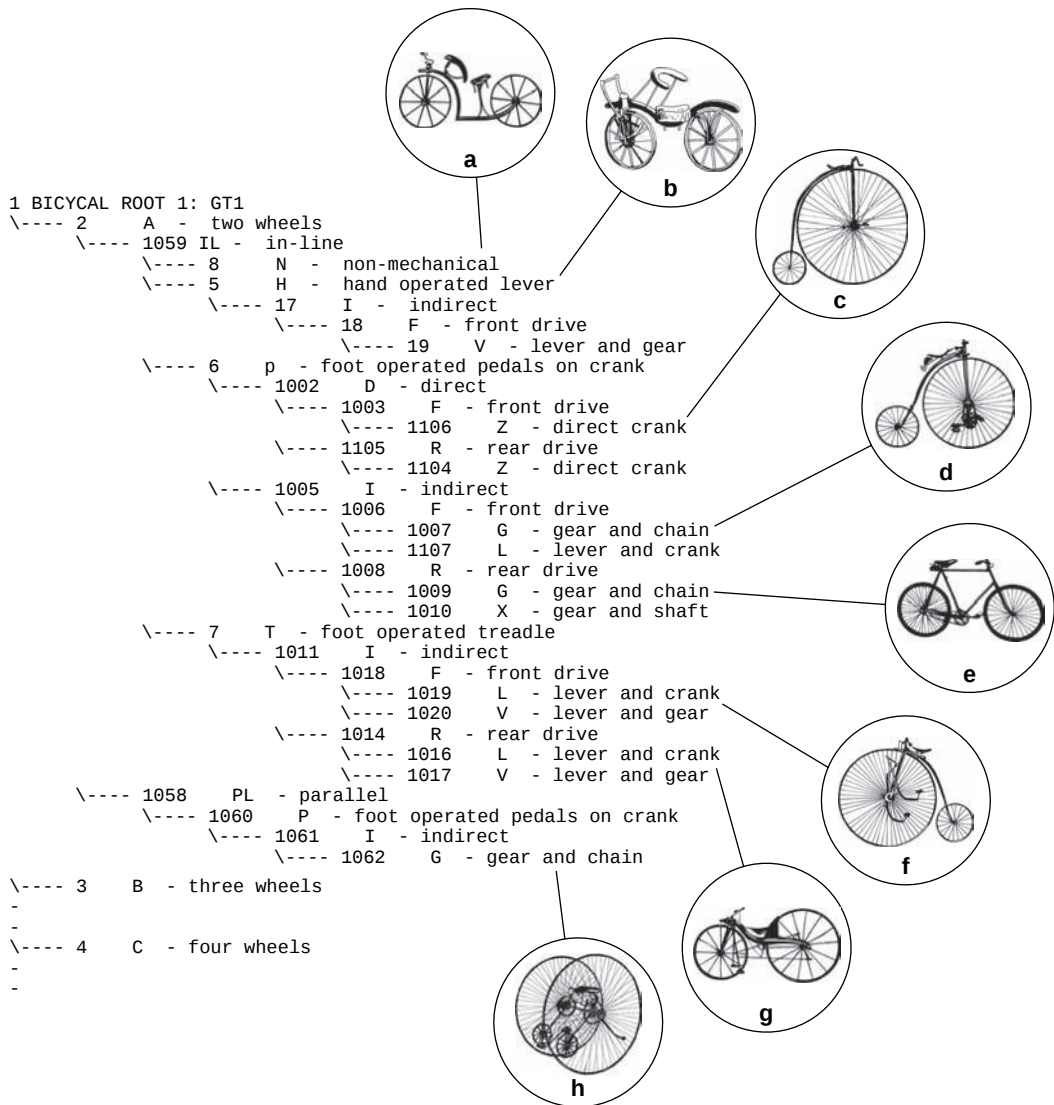


FIGURE 10.4 The bicycle design taxonomy with examples of leaf node occupants: (a) Ladies' Hobby-Horse, 1819; (b) Gompertz's hand-cranked draisine, 1821; (c) Rudge ordinary bicycle, 1884; (d) kangaroo bicycle, 1878; (e) Osmond safety bicycle, 1896; (f) Singer Xtraordinary bicycle, 1878; (g) McCall's rear-driven bicycle, late 1860s; (h) Otto bicycle, 1881. Sources: a, c, d, e, f, g, and h are redrawn from Caunter 1955, plates I, IV, V, VI, and X, by permission of Her Majesty's Stationery Office; b is redrawn from *Polytechnisches Journal* (June 1821).

The 199 images chosen all satisfy two criteria: clear visibility of the morphological and technological attributes and provision of dates of production and/or the date of the original image in the accompanying text. In cases where sources disagree about the production dates of the same bicycle, the average start and end dates are used.

CHRONOLOGICAL TAXONOMIC DIVERSITY

The third stage of our analysis is an exploration of the chronological patterning in how bicycle species populate the design space represented by our taxonomy. For this purpose, we follow Lyman and O'Brien (2000) in borrowing tools

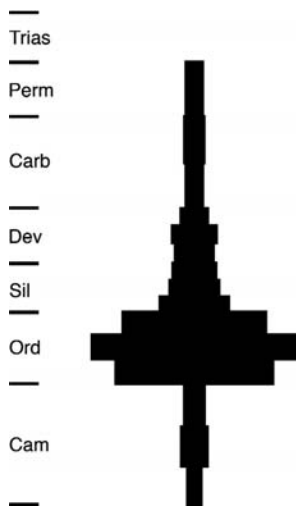


FIGURE 10.5 A biological clade diversity diagram showing the changing number of genera within the order *orthida* (drawn using data from Gould et al. 1977, figure 1).

developed by palaeontologists for the study of biological macroevolution—specifically, clade diversity diagrams and the clade diversity statistic known as “center of gravity” (Gould et al. 1977, 26–27). The reader is referred to Lyman and O’Brien’s (2000, 47–53) work for a detailed introduction. Here we simply reiterate the basic concepts and explain why we prefer an alternative terminology. Clade diversity diagrams (e.g., figure 10.5) depict the number of taxa present within a higher taxon (e.g., genera within a family) during each of a chronologically ordered series of discrete temporal intervals. The label “clade diversity” reflects the usual assumption in evolutionary biology that the higher taxon in question constitutes a monophyletic lineage. However, as already noted—and as was also the case in Lyman and O’Brien’s study of radios—we prefer not to make any assumption about the mode of bicycle evolution. We simply use these palaeontological tools to measure the diversity of designs within a given taxonomic level. Consequently, to prevent confusion, we prefer “chronological taxonomic diversity diagram” to refer to the diagrams that we construct. In similar vein, we label the set of subtaxa within a given higher taxon a “taxonomic set” rather than a clade. It is also worth noting that, although

outwardly reminiscent of the “battleship curves” traditionally used by archaeologists for seriation, chronological taxonomic diversity diagrams differ in that they depict the changing number of types rather than the changing number (or relative frequencies) of instances of a type (Lyman and O’Brien 2000, 47).

The center of gravity (CG) statistic was devised by Gould et al. (1977, 26) to provide “a measure of the relative position in time of the mean diversity.” It is calculated by scaling the duration of the taxonomic set’s existence from 0 at the time of origin to 1 at the time of extinction and then measuring the position of the mean diversity along this scale, where the diversity is the number of taxa present at each temporal interval. The utility of CG is that it can be used to discriminate (but see Mitchell and MacLeod 1988 and Gilinsky et al. 1989 regarding statistical significance) among three different macroevolutionary patterns: $CG < 0.5$ indicates rapid diversification followed by extinctions, as represented by a bottom-heavy clade diversity diagram such as figure 10.5 or a bottom-heavy chronological taxonomic diversity diagram such as figure 10.6; $CG = 0.5$ indicates a steady rate of diversification followed by a steady rate of extinction, as represented by a symmetrical diagram; and $CG > 0.5$ indicates a relatively late increase in diversification, as represented by a top-heavy clade diversity diagram or chronological taxonomic diversity diagram.

Using chronological taxonomic diversity diagrams and the CG statistic, we can explore the chronological manner in which bicycle species populate the design space represented by our taxonomy and, in particular, whether that occurs differentially at higher versus lower taxonomic levels. The basic method involves counting the number of occupied leaf taxa within some specified range of taxonomic levels and then using this count to plot the appropriate chronological taxonomic diversity diagram(s) and to calculate value(s) of CG. For example, in an analysis of levels 0 to 3, we take the first temporal interval and count how many taxa at level 3 are occupied (or have subtaxa that are occupied) by at least

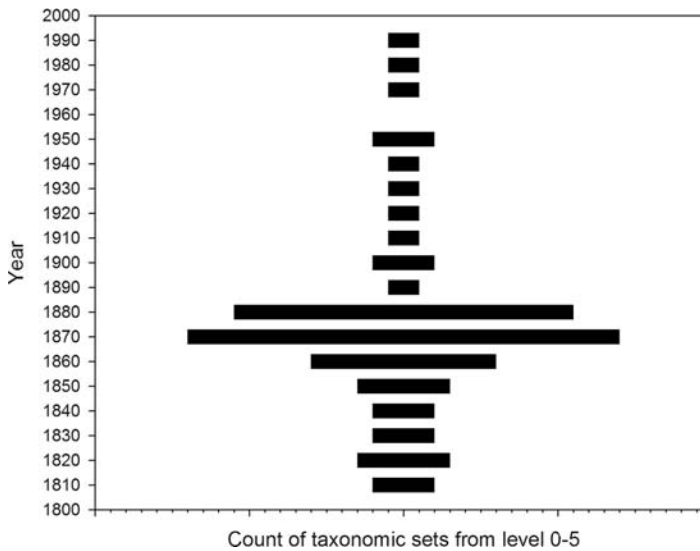


FIGURE 10.6 Chronological taxonomic diversity diagram for levels 0–5 of the generatively entrenched bicycle taxonomy.

one bicycle design. We then back up the hierarchy to level 2 and count the number of taxa that are directly occupied; we do not count those that are occupied by subtaxa at level 3, as these are already accounted for. This summation of occupied leaf taxa continues until we reach the specified starting level. The final count constitutes the taxonomic diversity for that temporal interval. The chronological pattern of diversity is obtained by repeating the process for all remaining temporal intervals.

Note that in any given analysis the number of diagrams and the number of CG values is equal to the number of occupied taxa at the highest taxonomic level specified. Figure 10.6 shows the chronological taxonomic diversity diagram for taxonomic levels 0 (the root) to 5 (one removed from the deepest level). This particular analysis is broadly analogous to plotting a biological clade diversity diagram for genera within a kingdom, although it differs by the inclusion of leaf taxa at higher levels than the lowest specified (because our bicycle taxonomy is not of uniform depth) and by measuring the diversity of designs rather than the diversity of clades *sensu stricto*.

Table 10.2 shows the values of CG for all the ranges analyzed—that is, levels 0–5, 1–5, 2–5, and 3–5. Figure 10.7 plots the mean value of CG for each range. Figure 10.6 shows that diversity across taxonomic levels 0–5 exhibits the bottom-

heavy macroevolutionary pattern associated with a biological adaptive radiation: early diversification followed, in this case, by extinction and relative stasis. This result, mirrored in the low CG of 0.378, suggests that there may well be similarities in the way that biological evolution and technological “evolution” explore design space. Furthermore, inspection of our populated bicycle taxonomy reveals that this early diversification occurs at higher taxonomic levels. Figure 10.7 provides a preliminary indication that there may be a trend in which the mean value of CG increases across the taxonomic ranges 0–5, 1–5, 2–5, and 3–5, respectively. If so, then it would appear that the macroevolutionary pattern associated with the exploration of progressively smaller regions of design space (i.e. within progressively lower taxonomic classes) is decreasingly like that associated with adaptive radiation and increasingly like that associated with relatively equal rates of diversification and extinction. Although we do not make any claims about the precise nature of this trend (i.e., whether it is linear or otherwise), we do nevertheless tentatively interpret it as evidence that exploration of bicycle design space did indeed proceed initially by long-jump adaptation on a relatively rough fitness landscape and subsequently by hill climbing on a smoother fitness landscape, as proposed by Kauffman.

TABLE 10.2. *Mean Values of CG*

TAXONOMIC LEVELS	CG PER TAXONOMIC SET	MEAN CG
0–5	0.378	0.378
1–5	0.429	0.467
	0.430	
	0.542	
2–5	0.500	0.440
	0.434	
	0.542	
	Null	
	0.375	
	0.374	
	0.417	
3–5	0.5	0.491
	0.402	
	0.617	
	0.500	
	Null	
	0.425	
	0.500	
	Null	
	Null	
	0.542	
	0.500	
	0.500	
	Null	
	Null	
	Null	
	0.500	
	0.389	
	0.500	
	0.500	
	0.500	

It is worth emphasizing that *individual* chronological taxonomic diversity diagrams or center-of-gravity statistics do not directly measure both aspects of diversification relevant to our question: they can measure changes in diversity but not changes in disparity. In other words, they can measure whether diversification occurs early or late, but not whether it occurs early at higher taxonomic levels and subsequently at lower taxonomic levels. For example, our chronological taxonomic diversity analysis across levels 0–5 cannot by itself distinguish whether the occupied leaf taxa in a given chronological unit are relatively

sparsely distributed across all three level 1 taxa or densely distributed in just one of those higher taxon. The question of whether diversification occurs at higher or lower taxonomic levels can only be addressed by chronological taxonomic diversity analysis if it is applied at multiple levels, as we have done here. A better approach would be to devise a metric that directly measures chronological variability in the distance between newly occupied locations in design space—in other words, a metric that directly measures disparity rather than just diversity. We will report on an attempt to do exactly this in a future work.

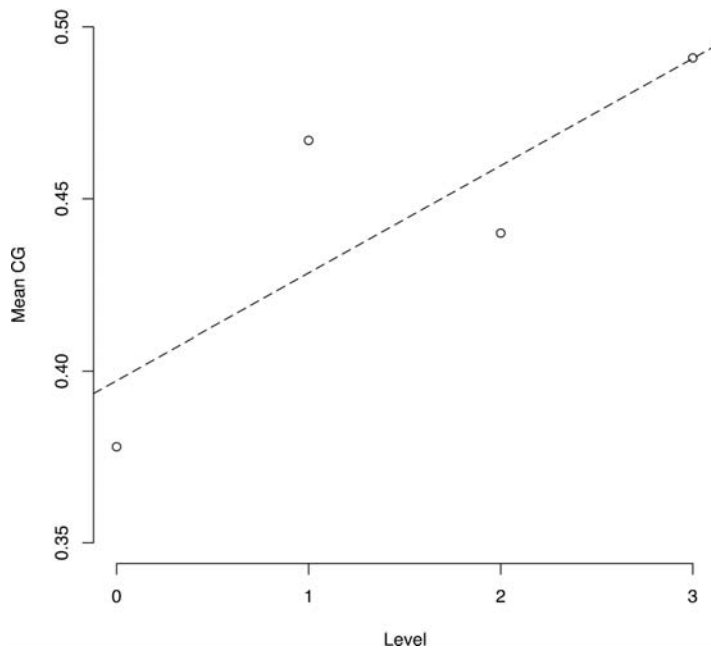


FIGURE 10.7 Linear regression on the mean value of CG for the following ranges of taxonomic levels: 0–5, 1–5, 2–5, 3–5 ($r^2 = 0.68$).

CONCLUSION

The basic question posed at the outset of our investigation was whether the exploration of technological design space produces the kind of macroevolutionary patterns that are well documented in biological evolution. Given the results of our chronological taxonomic diversity analysis, we tentatively conclude that it does, at least in the case of the bicycle. Furthermore, we suggest that this study supports Kauffman's previously untested assertion that both biological and technological evolution proceed by early diversification at higher taxonomic levels, followed by later diversification at lower taxonomic levels. We do, however, caution against extrapolating too widely from bicycles to other technologies. In particular, it is possible that the fitness landscape associated with bicycle design has relatively few peaks compared with some other technologies because the requirement of a close coupling with human anatomy and physiology provides an unusually severe constraint on the range of viable alternatives (see Minetti et al. 2001 for possible evidence for this). If so, we would not necessarily expect to

see the dramatic homing in on a relatively small portion of design space replicated across all technologies.

Finally, it is worth reiterating that this chapter is primarily about the exploration of design space, not the reconstruction of phylogeny. In that sense, it has more in common with Lyman and O'Brien's (2000) analysis of radio diversity or, indeed, Layton's (2000, 262–266) invocation of Kauffman's ideas in his discussion of the evolution of farm technology, than it does with many of the evolutionary analyses reported in recent collections such as Lipo et al.'s (2005) *Mapping Our Ancestors* and Mace, Holden, and Shennon's (2005) *The Evolution of Cultural Diversity: A Phylogenetic Approach*. Whether the evolutionary process driving the exploration of bicycle design space produces monophyletic lineages is interesting but was not our concern here; rather, we wanted to know whether that exploration occurs by breadth-first search, producing diversification at higher taxonomic levels (an increase in disparity), followed by extinctions and subsequent local search, leading to a reduction in taxonomic diversity (a decrease in disparity). For this reason, we further

developed Lyman and O'Brien's use of clade diversity statistics for the analysis of technological evolution by calculating them for different levels in a hierarchical taxonomy designed to map the design space populated by our artifacts (bicycles). This multilevel analysis is the principal methodological contribution offered in this chapter.

Acknowledgments. We are grateful to the UK Arts and Humanities Research Council (AHRC) for funding Jay Venti's work on this project, initially through the AHRC Centre for the Evolutionary Analysis of Cultural Behaviour (CEACB) and more recently through the AHRC Centre for the Evolution of Cultural Diversity (CECD); James Steele kindly facilitated the latter. We would also like to thank Stephen Shennan and members of the CECD Culture Club for discussions that have helped hone our thinking. Mike O'Brien and Robert Layton provided a number of useful comments that helped us identify several possible sources of confusion in the presentation of our work. Needless to say, we are responsible for any remaining errors of omission or commission.

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ELEVEN

Innovation Diffusion and Traveling Waves

James Steele

IN THIS CHAPTER, I will examine the dynamics of innovation diffusion, to illustrate the difficulty of using changing frequency distributions to diagnose a particular social learning process. I begin by discussing an influential model of new product diffusion taken from the marketing science literature (Bass 1969). This model estimates the importance of social imitation (or contagion) in the temporal evolution of frequencies of adopters for new consumer durables. This model has some similarities to the social learning components of a model subsequently proposed by Henrich (2001) in anthropology. Limiting the discussion to empirical innovation diffusion in modern market economies, I propose that the patterns of temporal evolution of adoption rates explained by social transmission bias in the Bass and Henrich models can also be explained by economic inequalities that determine optimal adoption timing when the new product shows price decline over time and/or some improvement in performance. I suggest, further, that these two contrasting explanations (social contagion and economic inequality) can be applied to the situation where social contact frequencies and/or economic inequalities have spatial dependence, and that in such

cases, the two explanatory models can produce similar spatiotemporal patterns of adoption diffusion. I illustrate these general observations with data on the diffusion of two recent agricultural innovations in the twentieth-century United States. My conclusion is that temporal and spatiotemporal patterns of innovation diffusion do not, in themselves, enable us to diagnose the importance of different kinds of bias in the decisions of adopters about the optimal timing of adoption. This diagnosis requires additional contextual information about a suite of economic, sociocultural, and environmental variables.

THE BASS MODEL AND ITS CRITICS

Typically in the innovation adoption literature, diffusion of an advantageous technology by independent assessment of efficacy is expected to produce an r-shaped cumulative growth curve, while diffusion by imitation of prior adopters is expected to produce an S-shaped cumulative growth curve (Bass 1969). Bass's influential model proposes that the population of adopters can be divided into early adopters ("innovators") and imitators, and that the shape of the cumulative adoption curve will vary as a function of their relative importance.

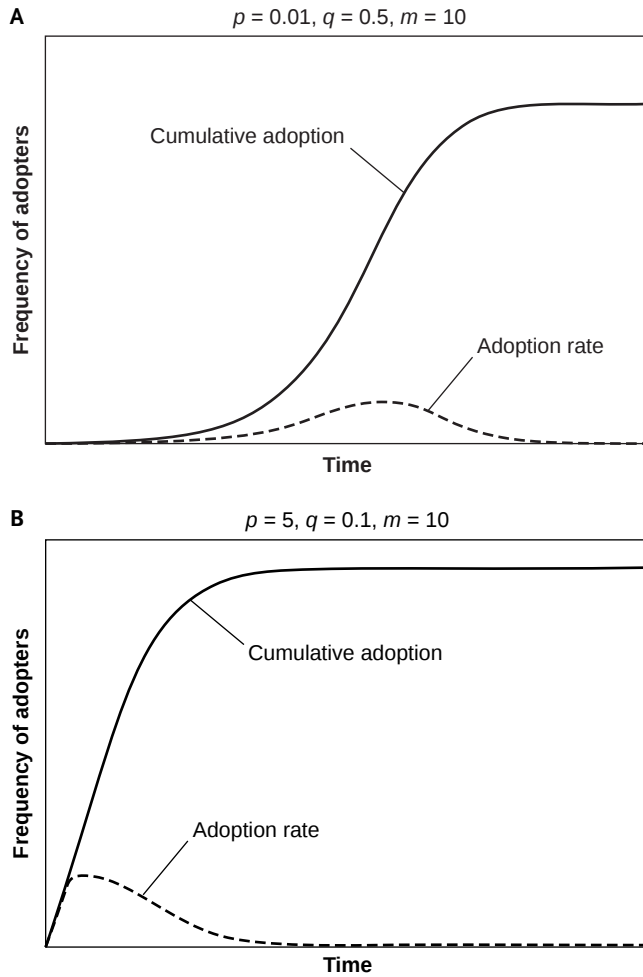


FIGURE 11.1 Rate of innovation adoption as a function of time, with different weights for the innovation coefficient (p) and the imitation coefficient (q): (a) $q > p$, and (b) $q \leq p$.

The Bass model includes an innovation coefficient, p , representing the fraction of the population who will initially adopt the innovation regardless of the availability of demonstrators, and an imitation coefficient, q , representing the fraction of the population whose choice is determined by the number of previous adopters. The basic model states that

$$P(t) = p + (q/m)Y(t),$$

where P is the probability of adoption by those who have not yet adopted at time t , p is a constant proportional to the initial number of innovators, q is a constant proportional to the rate of imitation, m is the size of the potential adopting population, and $Y(t)$ is the cumulative propor-

tion of previous adopters at time t . This can then be expressed as a population rate of increase (Van den Bulte 2002):

$$dN(t)/dt = [p + (q/m)N(t)] [m - N(t)],$$

where $N(t) = mY(t)$, the cumulative number of adopters.

In cases where $q > p$, adoption will increase to reach an internal peak before declining (figure 11.1a), leading to an S-shaped cumulative adoption curve. In cases where $q \leq p$, adoption rates will be at their maximum initially and then tail off (figure 1b), leading to an r-shaped cumulative adoption curve.

Empirically, the parameters p , q , and m can be estimated from discrete time series data by

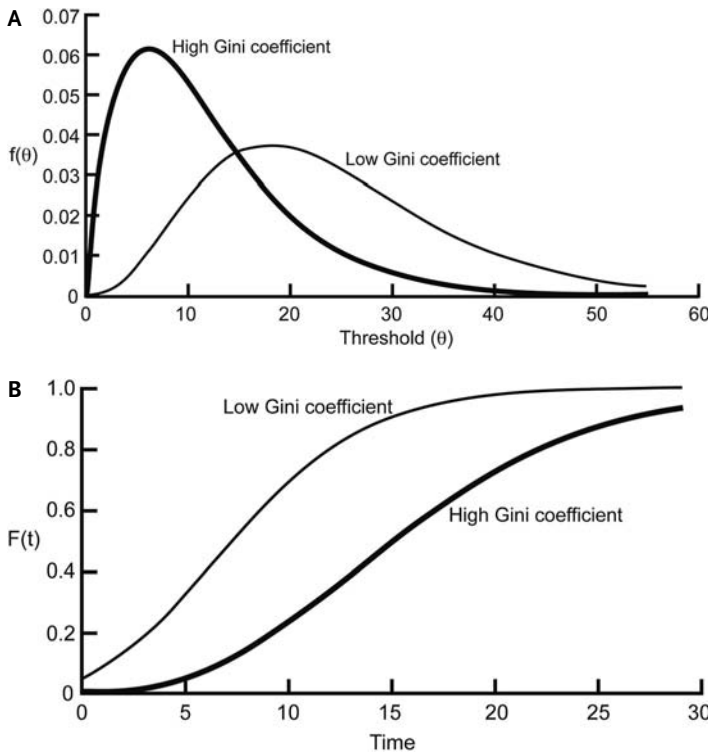


FIGURE 11.2 Price threshold distributions for adoption with high and low income inequality (Gini coefficient), and the corresponding cumulative adoption curves with decreasing prices over time (from Van den Bulte and Stremersch 2004).

regression techniques (Bass 1969). Taking the adoption rate (S) at time t as

$$S(t) = pm + (q - p)Y(t) - q/mY^2(t)$$

and using the analogue form

$$S(t) = a + bY_{(t-1)} + cY_{t-1}^2,$$

where Y_{t-1} is the cumulative number of adopters at $t - 1$, and then solving for a , b , and c using regression techniques, one can derive p , q , and m as follows: $m = (-b \pm \sqrt{b^2 - 4ca/2c})$, $p = a/m$, and $q = -mc$ (Bass 1969). The empirical ratio q/p gives an index of the relative importance of initial independent innovation and of subsequent imitation in the diffusion of a particular new cultural trait, and it is a shape parameter for the cumulative adoption curve.

Empirical analysis of the shapes of adoption curves in well-documented cases suggests that imitation is a much more influential mechanism of adoption than independent assessment of efficacy (Sultan, Farley, and Lehmann 1990), but the raw

data on which such inference is based—a preponderance of S-shaped cumulative curves—could also represent heterogeneity in the economic factors determining individual adoption timing. This is not accounted for in the Bass model. The assumptions required to generate S-shaped curves in a heterogeneous population using independent assessment are illustrated in figure 11.2, from Van den Bulte and Stremersch (2004), who address effectively the estimation of the importance of contagion and of heterogeneity of propensity in empirical cases. Figure 11.2 shows two theoretical distributions of adoption thresholds for a new product in populations with different levels of income inequality (as indexed by the Gini income concentration coefficient), and the corresponding cumulative adoption curves when the utility value of adoption increases with time (for instance, because of price decline). Both are S shaped, but the shape reflects income heterogeneity and not contagion-diffusion. The interpretation of S-shaped curves in the Bass model only applies in cases where there is population homogeneity in the

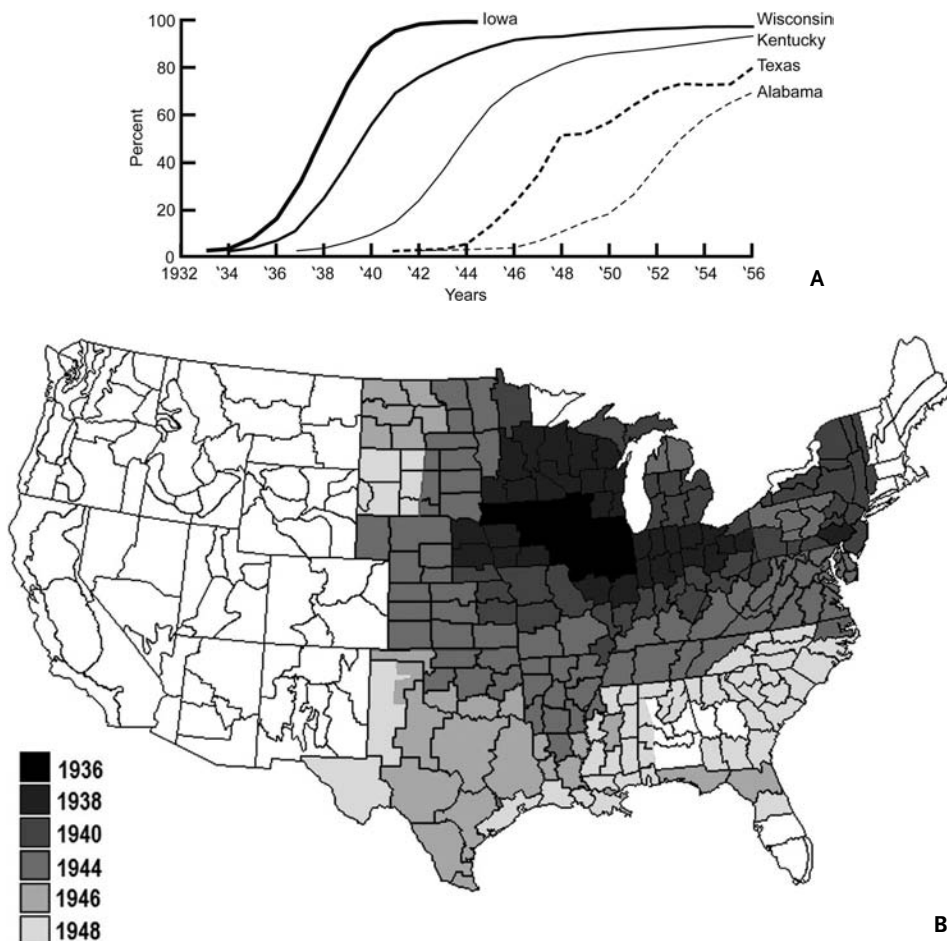


FIGURE 11.3 (a) Percent of total corn acreage planted with the hybrid strain, by state (from Griliches 1957, figure 1). (b) Diffusion of hybrid corn usage, showing areas that planted 10 percent or more of their corn acreage to hybrid seed at successive time intervals (redrawn after Griliches 1960b, figure 3).

economic factors determining the utility threshold for adoption subsequent to exposure.

A DUAL INHERITANCE APPROACH

Predictions of innovation diffusion rates also exist in the dual inheritance literature and include terms that relate to the strength of cultural selection. S-shaped curves can be simulated by a growth function in which, in the simplest treatment, the intrinsic rate of increase is given by a term $\beta(w_1 - \hat{w})$:

$$\Delta p = p(1 - p)\beta(w_1 - \hat{w}),$$

where p is the frequency of the cultural variant, β a rate parameter, and w_1 and $\hat{w}$ denote payoff to the behavior of interest and the average payoff, respectively (McElreath and Henrich 2007). This treatment of the payoffs omits any social interaction term more complex than random choice of potential models in a perfectly mixed population. In a well-studied example of the diffusion of hybrid seed corn in 1940s Iowa, where the new strain brought a 20 percent gain in yield, the rapid empirical diffusion rate implies a high value for β , $\beta \gg 1$ (McElreath and Henrich 2007; cf. figure 11.3). The new high-yielding variant spread more quickly than

would have been the case if seed from the old and new strains had been selected for each annual planting proportional to their frequency at each preceding harvest, without any preferential selection by farmers of the new strain. In this case, β denotes an assessment bias that amplifies the payoff differential in the randomly mixing situation, and it therefore measures the strength of cultural selection. If the S shape reflects a social contagion process, then β measures the strength of bias in indirect biased transmission. If the S shape reflects heterogeneity in other factors influencing adoption timing, then β measures a transformation of the payoff differential in individuals' direct assessment of efficacy.

Henrich (2001) has proposed an explanation of the shape of the Iowa hybrid corn diffusion curve in terms of biased transmission, with particular emphasis on conformist bias. He analyzes a curve showing the cumulative frequency of individual adopters in two Iowa farming communities, and his interpretation may well apply. However, in principle, both his curve of Iowa adopters and the curves shown in figure 11.3 could be generated if farm size was a factor affecting the time of first contact with seed corn suppliers (because the latter preferentially targeted the larger units, where the greatest gains were to be made), and if farm sizes had the distribution seen in figure 11.2. There is a further complicating factor in that the curves in figure 11.3 relate to acreage and not to the decisions of individual farmers (which are the focus of explanation for these models). If farm sizes are uniformly distributed or uncorrelated with adoption timing, then the acreage planted with the new strain can reasonably be taken as a proxy for the frequency with which individual farmers decided to adopt. However, if farm size and adoption timing are correlated, then there will be a systematic error that needs to be controlled for. Specifically, if larger farms adopt earlier, then the cumulative adoption curve for acreage will imply a larger growth coefficient than that of the underlying

cumulative frequency of individual farmers' adoption decisions.

SPATIAL DIFFUSION AND TRAVELING WAVES

Such treatments attempt to estimate the strength of cultural selection from the gradient of the adoption curve, but they omit any spatial dimension. In fact, when several regional adoption curves for the same cultural trait are plotted side by side, they can reveal a spatial lag in adoption consistent with a contagion–diffusion process. Figure 11.3 illustrates this, showing the adoption curves for hybrid corn in five midwestern and southern states at progressively greater distances from the eastern Iowa diffusion pole (or local origin), as well as the overall pattern for the United States in two spatial dimensions. Two things are immediately apparent: that lags seen when comparing arrival times in different regions would be consistent with a traveling wave contagion–diffusion explanation, and that the regional (state-level) adoption curves have different shapes and different slopes.

The basis of a contagion explanation of spatial lag is that adoption decisions are based on frequency of exposure to models, and proximity has an influence on social contact rate. If we imitate from among those whom we see most often, and if our interactions are most frequent with our neighbors, then behaviors spread by imitation will diffuse spatially in a wavelike fashion (like an infective disease epidemic).

There is, however, an alternative explanation of such spatial patterns. It may be that heterogeneity in economic factors determining optimal adoption timing has a spatial structure (e.g., with an adoption lag in more economically marginal areas where the fixed capital cost of investment in a new technology would represent a more significant investment burden). People may all be aware of the new technology, but adoption may show a spatial lag due to variation in the economic factors determining optimal timing of adoption.

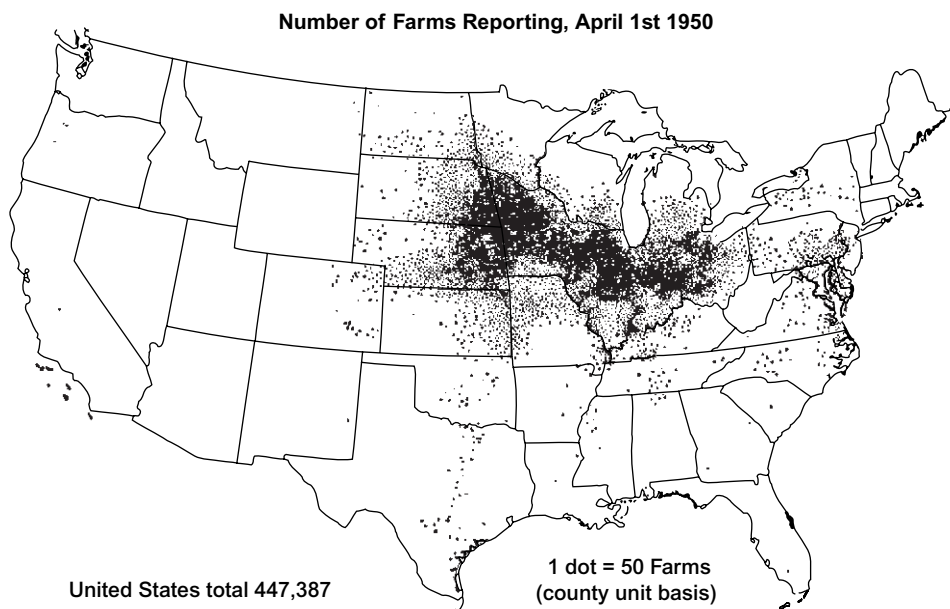


FIGURE 11.4 The density of corn pickers in 1950, as a measure of corn yield, with the Corn Belt clearly delimited (from Griliches 1960b, figure 5).

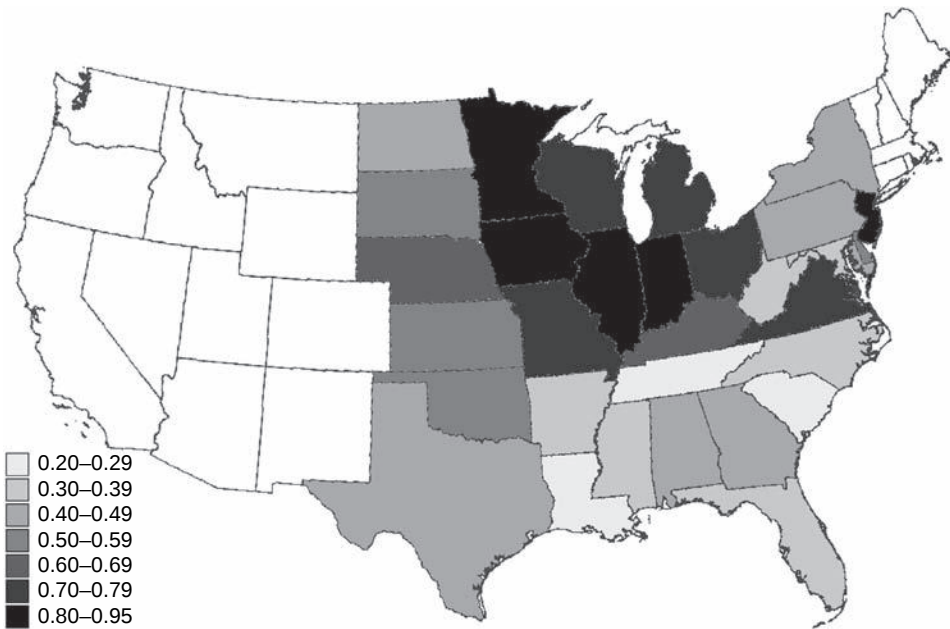
THE CASE OF HYBRID CORN ADOPTION IN THE UNITED STATES

In the case of the adoption of hybrid corn, Griliches (1960b) has argued that the observed delay reflects initial preferential targeting of the most profitable regions by seed corn producers, and an additional factor relating to regional variation in the allocation of effort on selective breeding of hybrids adapted to local conditions by agricultural experimental stations in different states. Figure 11.4 shows the density of corn pickers in 1950, as a measure of corn yield, with the Corn Belt clearly delimited. This region clearly corresponds to the zone of earliest commercial adoption of the hybrid corn, although the major innovation in its development actually took place in Connecticut. Griliches (1960b) also argued that differences in slopes of adoption curves between states (figure 11.3) reflected different levels of uncertainty about the gain in yield of the hybrid corn, with gains becoming apparent sooner in regions where absolute yield is higher (and thus where the typical percentage gain in yield from the new crop would be more immediately apparent). Dixon (1980)

has since confirmed the correlation of state-specific adoption rates with measures of average farm size and of the agricultural productivity of the land. The additional correlation among states between time of initial adoption and subsequent rate of growth (with late-adopting states also showing a slower rate of substitution by the new strain; see figure 11.5) is therefore suggestive of regional heterogeneity in economic thresholds and not of contagion-diffusion. Indeed, this spatial gradient in within-state substitution rates complicates interpretation of the graph and map of first adoption time, because these actually plot the date at which 10 percent or more of corn acreage was planted with the hybrid strain, and this will vary with substitution rates as well as with the true time of initial introduction.

Existing versions of the contagion explanation do not predict heterogeneity within and between populations in $\beta(w_t - \hat{w})$, and this is a limitation of that explanation in its present form. Henrich (2001) does, however, suggest that social contagion will be more likely to occur where individuals are less able to assess the efficacy of an innovation directly, and this would

A



B

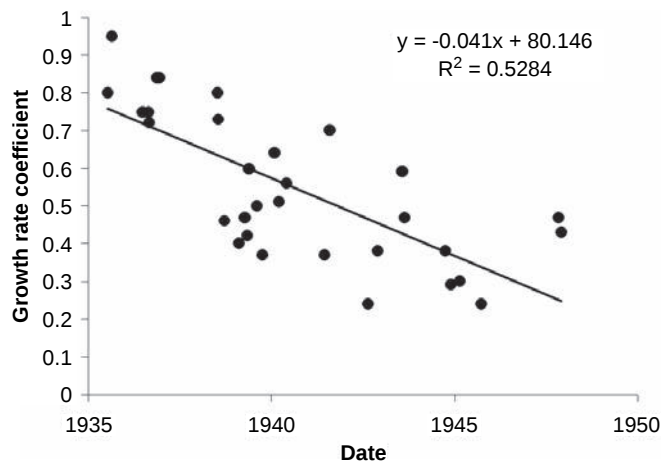


FIGURE 11.5 (a) Map showing within-state rates of increase in hybrid corn use. (b) Within-state rate of increase of hybrid corn use, plotted against the date of arrival in each state (the date at which hybrid corn reached 10 percent of all corn). Data from Griliches (1957) with revised growth coefficient estimates from Dixon (1980; coefficient b_2).

imply—following Griliches (1960a)—that the later-adopting states should also show a higher value for the q/p index (if we assume that adopters evaluate new products on the basis of information available within-state, and if we make the additional restricting assumption that there is no significant variation between states in internal heterogeneity of economic factors affecting adoption timing). This would therefore merit further investigation.

THE CASE OF TRACTOR ADOPTION (AND HORSE DEVOLUTION) IN THE UNITED STATES

The diffusion of tractor use in the United States is another case that illustrates these issues. A similar set of traveling wave profiles to those for hybrid corn can be recovered for the diffusion of the tractor in selected states in the American Midwest (figure 11.6), in this case reflecting

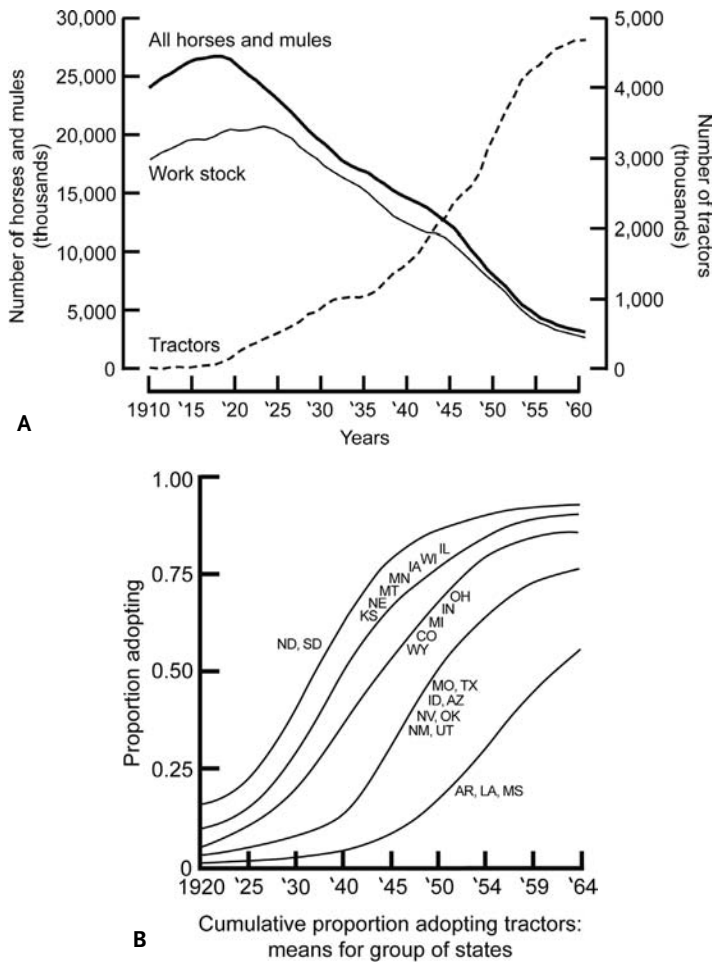


FIGURE 11.6 (a) Substitution of the tractor for the horse on farms in the United States, 1910–1960 (from Olmstead and Rhode 2001, figure 1). (b) Mean cumulative adoption curves for the tractor in groups of states in the U.S. central and mountain regions (from Morrill 1985, figure 2). (c) Distance from North Dakota against date of peak growth rate in adoption of the tractor in the U.S. central and mountain regions (approximated as the date at which adoption had reached 50 percent of market saturation), classified by state (distances between centroids of states; data from Casetti and Semple 1969 and Banks 1994). (d) Map of dates of peak growth rate in adoption of the tractor in states in the U.S. central and mountain regions (approximated as the date at which adoption had reached 50 percent of market saturation; data from Banks 1994).

increasing distance from an estimated diffusion pole in North Dakota (Casetti and Semple 1969).

The spatial gradient in diffusion of the tractor does not seem immediately compatible with a threshold distribution explanation. A graph of state-level substitution rates shows that their variation does not account for the spatial lag in onset of use (figure 11.7). By implication, late-adopting states were not characterized by greater uncertainty about the profitability of

adoption. However, according to Duffy-Martini and Silberberg (2004):

The diffusion of the tractor was not uniform across the US. As the tractor developed, various farming systems found them useful albeit in different decades. Very roughly, the small grain region and Far West were the earliest adopters. This farming system has an annual cycle of plow, plant and reap. Although the planting was usually done with horses, plowing and reaping could be done with tractors. The huge power needs of these tasks made the tractor a valuable

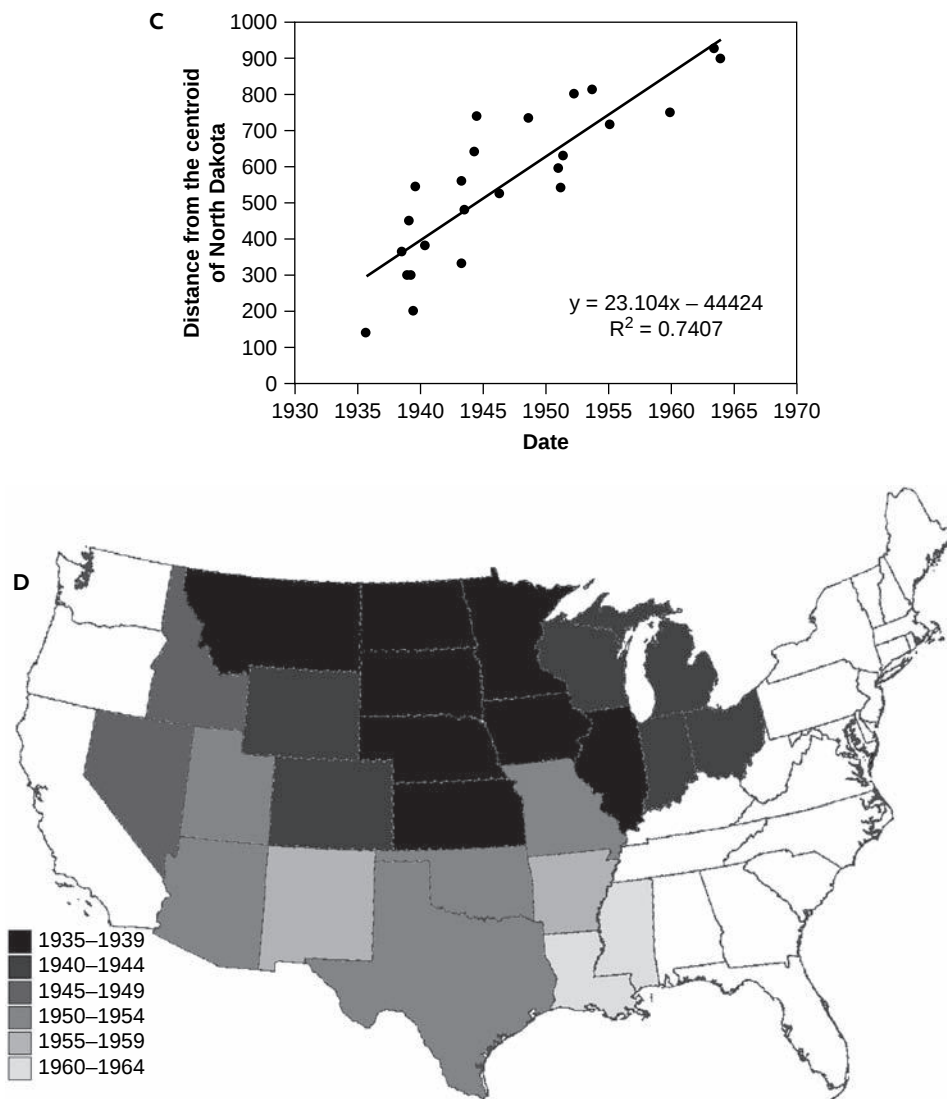


FIGURE 11.6 (Continued)

addition to the farm and reduced the number of horses needed. The more complicated farming system of the Corn Belt has a cycle of plow, plant, cultivate and hand harvest for crops. Because of smaller acreages and cultivation between the rows of corn, tractors did not displace many horses until the introduction of the Farmall tractor in 1925. The Cotton Belt did not find tractors competitive until the mechanical cotton picker allowed for the displacement of labor and horses in harvest. The eastern states' adoption was more individual as the evolution of the tractor and specific implements became available. Thus it is important to segregate the type of farming by region or even state.

This suggests that there may have been a north-west-southeast gradient in tractor adoption timing reflecting a time trend in the utility of adoption for different systems as the technology evolved (or as other input and output values changed), which could account for the pattern seen in figure 11.6 as an alternative to proximity-based contagion-diffusion. Casetti and Semple's data have been reanalyzed by several authors, including Cliff and Ord (1975) and Pfeifer and Deutsch (1980), who use more highly parameterized forecasting models. Morrill (1985) found additional effects of economic and environmental variables on adoption

FIGURE 11.7 Growth coefficient plotted against date of peak growth rate in adoption of the tractor (approximated as the date at which adoption had reached 50 percent of market saturation), classified by state (data from Banks 1994).

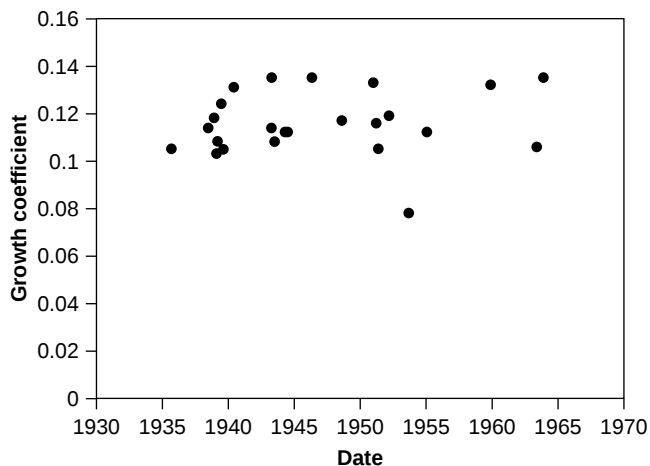
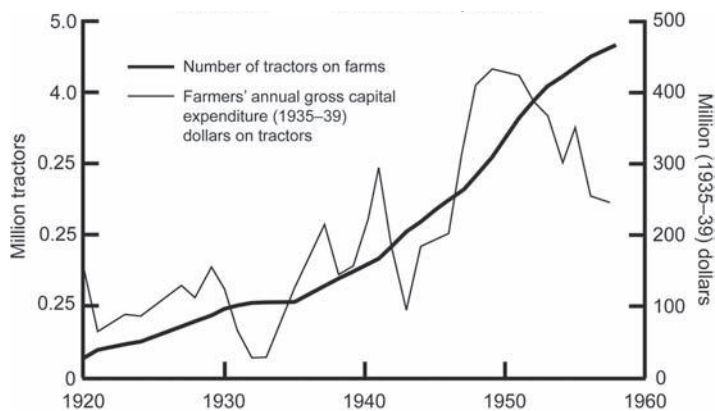


FIGURE 11.8 Tractors on U.S. farms: numbers and gross investment, 1920–1957 (from Griliches 1960a, chart 1).



lag—including per capita income, percentage of land in cereal crops, and winter temperature—that suggest a role for adoption threshold heterogeneity in space. Griliches (1960a) had already shown that the cumulative frequency curve for tractors on farms is an inadequate indicator of farmers' investment decisions in new machines, and it does not take account of either increases in designed use-life during the diffusion period or economic factors determining the prolongation of use-life through repair and maintenance. The empirical investment curve for new tractor purchasing (figure 11.8) is much less smooth and does not show the normal distribution of investment decisions over time predicted by the simplest form of a social contagion model (e.g., figure 11.1a, dashed line). Griliches (1960a) shows that investment

decisions were highly sensitive in the short term to cost/benefit ratios, taking account of farm output prices and rates of depreciation of the stock of machinery. This analysis of farmers' investment decisions at the national level suggests that even without any contagion effects, we should expect both heterogeneity of adoption timing at the state level and spatial heterogeneity in optimal adoption timing at larger scales (producing traveling waves).

At the within-state level, Mattingly (1987) interprets the pattern seen in Illinois (figure 11.9) as a contagion process, but the spatial lags also correspond broadly to gradients of decreasing average farm sizes and decreasing levels of cash grain farming (figure 11.10), both of which may correlate with higher thresholds for investment in a fixed-cost innovation of this kind. It may be,

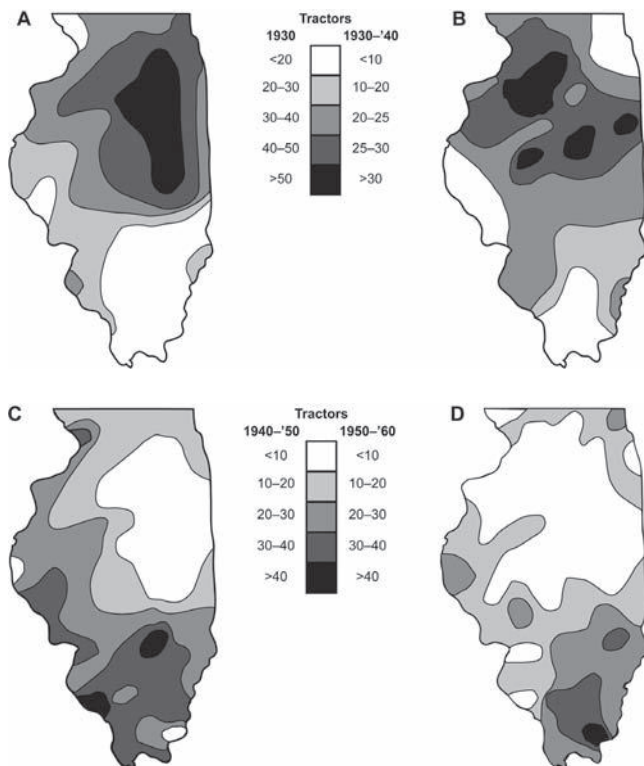


FIGURE 11.9 The diffusion of the tractor in Illinois (from Mattingly 1987). The first (1930) map shows the percentage of farms with tractors; the subsequent maps show the difference in percentages between the beginning and end of the indicated time periods.

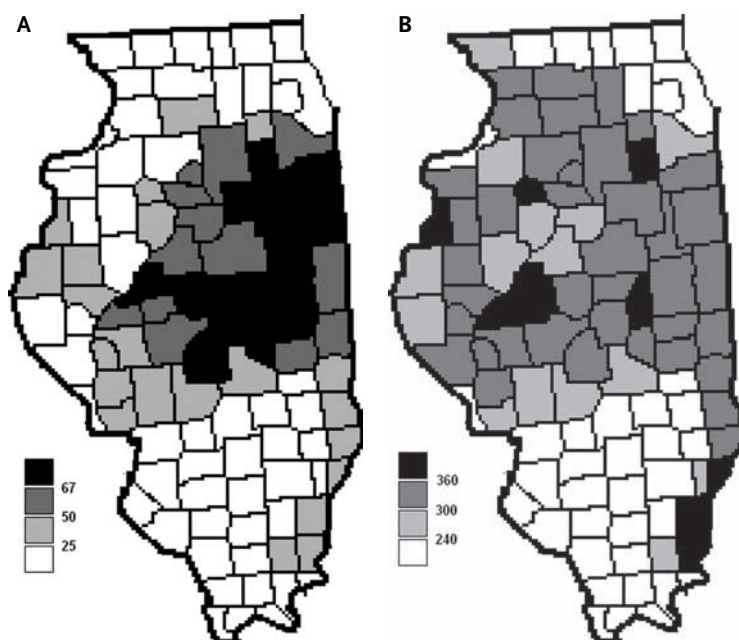


FIGURE 11.10 (a) 1949 data on percentage of farms focused on cash-grain cropping, by county (redrawn after Hart 1986, figure 13). (b) Average farm size in acres, by county, 1982 (redrawn after Hart 1986, figure 5). Overall in the twentieth century, farm size increased, but the county-by-county pattern of relative sizes for Illinois was conserved: 1939 farm sizes predict 1982 farm sizes with high accuracy ($r = 0.94$; Hart 1986).

therefore, that availability of the new technology was simultaneous throughout the state but that adoption showed a wavelike diffusion pattern because of spatial heterogeneity in economic factors affecting adoption timing. The pattern itself cannot resolve this, and further analysis is required of the spatial variation in adoption times in relation to economic and social factors.

CONCLUSIONS

These case studies illustrate the difficulty of interpreting a pattern as evidence of a particular process. S-shaped cumulative adoption curves may indicate indirect biased transmission or social contagion, but only where the population is homogeneous with regard to price and utility thresholds for innovation adoption. Where there is heterogeneity, an adoption threshold distribution can produce exactly the same curves without contagion. Spatial traveling waves may also indicate a local contagion–diffusion process, but again, only where the population is homogeneous with regard to adoption thresholds. Where there is spatially structured heterogeneity, the same spatial lag pattern may be observed without contagion. Neither pattern is sufficient to demonstrate one or the other process, in the absence of supplementary information about individual and environmental variation.

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TWELVE

Explaining Global Patterns in Lower Paleolithic Technology

SIMULATIONS OF HOMININ DISPERSAL AND CULTURAL TRANSMISSION USING STEPPING OUT

Sam Smith, John Hughes, and Steven Mithen

THE ARCHAEOLOGICAL evidence from the Lower and Middle Palaeolithic does not easily lend itself to fine-grained quantitative models of cultural transmission, even though the processes of social learning can readily be appreciated as important for gaining an understanding of variability in stone tool technology (Mithen 1994, 1999; Shennan and Steele 1999). Models such as that used for examining variation in Neolithic ceramics by Shennan and Collard (2000) require a level of chronological resolution that is simply not possible for the Lower and Middle Palaeolithic archaeological records. Moreover, the ecological, social, and cognitive contexts in which such stone artifacts were manufactured are often unclear, preventing reasonable assumptions to be made about the likely nature of cultural transmission—such as whether this involved direct teaching, language-mediated instruction, or mere passive observation. While the Lower and Middle Palaeolithic archaeological records may not be amenable to fine-grained models of cultural transmission,

their unique value is the provision of a global and long-term perspective on the nature of culture change.

In this chapter, we use a simulation model for hominin dispersal and cultural transmission to contribute toward the interpretation of global patterns of variability in stone tool technology. The issues we specifically address are the so-called Movius line of eastern Asia, beyond which Acheulean (Clark's 1961 mode 2) and Levallois (mode 3) technology is either absent or extremely rare, and the relatively late appearance of the Acheulean in Europe.

GLOBAL PATTERNS IN LOWER PALEOLITHIC LITHIC TECHNOLOGY

While the stone tool technology of premodern hominins has some variability in technology and typology, its most startling feature is the cultural continuity found across large expanses of space and time. This is most dramatically illustrated by the Acheulean tradition that appears by

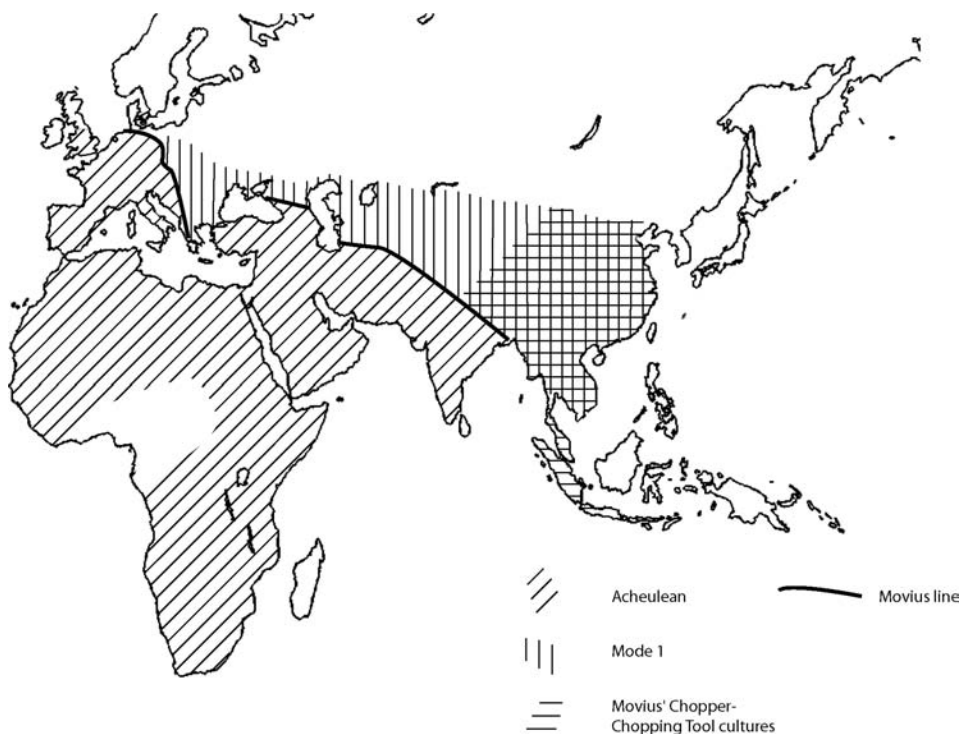


FIGURE 12.1 Map showing distribution of Lower Palaeolithic industries. Redrawn after Schick 1994, 571 (figure 26.1).

1.6 million years ago (mya) in Africa (Asfaw et al. 2002) and is still persistent throughout much of Africa and western Eurasia 250,000 years ago. As such, Lower and Middle Palaeolithic technology contrasts with that of modern humans, which shows significantly higher spatiotemporal variability. Some argue that we should consider Lower and Middle Palaeolithic stone tools as biological rather than cultural traits, to be analyzed and interpreted in the same manner as genetic markers (Foley 1987). While there may be some merit to this, reference to the processes of cultural transmission and social learning are just as essential for understanding Lower and Middle Palaeolithic technology as they are for both modern humans and chimpanzees.

The Lower and Middle Palaeolithic record allows us to consider hominin behavior at a global scale. One of the most evident patterns in the archaeological record is the so-called Movius line: “perhaps the most salient feature characterizing the Lower Palaeolithic culture complex of Southeastern Asia, Northern India and China

as a whole is the absence of certain characteristic types of Lower Palaeolithic implements (hand axes and Levallois flakes), as much as it is the presence of others (choppers and chopping tools)” (Movius 1969, 72; figure 12.1).

While it is almost a half century since Movius made this claim, the pattern remains essentially unchanged (Schick 1994). We do, of course, have a quite different perspective on the archaeological record, focusing on individuals rather than “culture complexes” (Mithen 1993; Gamble and Porr 2005). We also now place greater emphasis on the flakes rather than the cores within what Movius (1948, 1969) called the “chopper and chopping tools cultures” of South and Southeast Asia, defining these as “pebble/flake” assemblages.

Yi and Clark (1983) made a strong critique of the Movius line, arguing that sites such as Chon-Gok-Ni in Korea have bifacially made artifacts. But as Schick (1994) explained, while some bifacial flaking may have been used in their manufacture, such tools do not fall into the Acheulean

tradition that is characteristic of Africa and western Eurasia. Yamei et al. (2000) provide more persuasive evidence for Acheulean-like technology beyond the Movius line, in this case coming from the Bose Basin, South China. But as they note, this has a very limited presence, being found in a stratigraphically restricted interval dating to about 803,000 years ago. As such, it contrasts to the widespread pattern found in similar fluvial terrace localities in western Eurasia where Acheulean artifacts are spread across numerous stratigraphic levels. Consequently, the question we must ask today is essentially the same as that which Movius posed: “Why did the Acheulean, with . . . [its] . . . very strong, powerful tradition of tool-making, maintained by hominids through Early and Middle Pleistocene times across vast reaches of time, tremendous distances, and presumably drastically different environment zones, never really penetrate the eastern reaches of Asia?” (Schick 1994, 586).

Explanations for the Movius line are manifold and include proposals about the absence of suitable stone for the manufacture of bifaces, the availability of bamboo as an alternative raw material (Boriskovskii 1968; Pope 1989), the loss of the knowledge to manufacture Acheulean artifacts within small and isolated East Asian populations (Schick and Toth 1993), different functional requirements for stone artifacts in Southeast Asia, and geographic barriers to the spread of Acheulean technology (see Schick 1994 and Corvinus 2004 for reviews). Yamei et al. (2000, 287) suggest that even with their evidence from the Bose Basin, “the flow of population and cultural information across the [Movius] line may not have been extensive.”

The case for geographic barriers to the spread of either Acheulean artifact-bearing hominins or the ideas/practice of Acheulean technology has gained weight with our improved understanding of hominin dispersals from Africa. The recent dates from Dmanisi (1.8 mya; Gabunia et al. 2000) and Indonesia (1.8 mya; Swisher et al. 1994) demonstrate that the initial Eurasian dispersal of *Homo erectus* (*sensu lato*) was undertaken

before the African advent of Acheulean technology, the earliest occurrence of which is at Konsu Gardula (Ethiopia) about 1.6 mya (Asfaw et al. 2002). This is a significantly different view of the situation from that which prevailed only a decade ago when the Acheulean was thought to predate and even drive Eurasian dispersal. We no longer need to consider explanations for the Movius line that propose that Acheulean technology became “lost” from the cultural repertoire of hominins dispersing to Southeast Asia. In contrast, our attention must now focus on assessing why Acheulean technology did not spread to eastern Asia by cultural transmission, despite being present in much of the Pleistocene world. One potential explanation is that populations to the east of the Movius line were relatively isolated from Acheulean populations to the west throughout the entire Pleistocene, and this isolation prevented the diffusion of technological traditions.

The archaeological evidence from the earliest occupation of Europe raises similar issues to the Movius line in Southeast Asia. While we have hominins at the Gates of Europe by 1.8 mya (Lordkipanidze, Bar-Yosef, and Otte 2000), occupation within Europe itself remains dated to 0.8 million years at the earliest (Carbonell et al. 1995; Parfitt et al. 2005). The earliest European sites are associated with a pebble/flake technology, even though these sites are 0.8 million years after the first appearance of the Acheulean in Africa. One possible explanation for their absence prior to this date is that a constraint existed on the cultural diffusion of this technology from Africa that became relaxed for Europe at 0.5 mya but that persisted for eastern Asia.

To explore whether geographic constraints may explain the global pattern of hominin technology, we need to take into account the processes of hominin dispersals from Africa and the cultural transmission between populations. The key question to ask is whether the most parsimonious assumptions about these processes can lead to patterns of cultural variability similar to those seen in the archaeological record. To ask such questions, we use a modified version of the Stepping Out model for hominin dispersal.

INCORPORATING CULTURAL TRANSMISSION INTO STEPPING OUT

Stepping Out is a computer simulation model developed by Mithen and Reed (2002) to examine the dispersal of *H. erectus* out of Africa, beginning about 2.0 mya. In Stepping Out, the Old World is divided into grid boxes, and each grid box is either occupied or unoccupied by hominins. The simulation begins with a “seed” population in East Africa at a date of 2 mya and then allows hominins to populate adjacent grid squares according to a suite of algorithms relating to colonization, competition, and extinction that draw on the vegetation type, proximity to the coast, and orography of those squares. In Mithen and Read (2002), the probability of extinction of a population within a grid square, P_{ext} , was sensitive to the climatic state. In a subsequent version of Stepping Out, one of which is used in this study, the climatic sensitivity has been incorporated directly into changes in the vegetation patterns (Hughes et al., 2007).

The methodology incorporated into Stepping Out for modeling cultural variability is equally applicable for modeling genetic variability. As such, it has been used by Hughes and Smith (2008) to interpret variation in the skeletal record of *H. erectus*, notably the morphological contrasts between African and Asian specimens. Indeed, the model data included in this chapter were originally presented and described in Hughes and Smith (2008) in the context of a simulation of gene flow among Pleistocene hominin groups.

The cultural component in Stepping Out models cultural variability at the population scale, in terms of a suite of cultural trait frequencies associated with each occupied grid square. It incorporates the processes of cultural drift and cultural mixing from interacting/interbreeding populations, but it does not include cultural selection. The “culture” of a *H. erectus* population within a Stepping Out grid square is measured by a set of twenty cultural trait frequencies $\{f^1, f^2, f^3, \dots, f^{20}\}$, with values between 0.0 and 1.0. The choice of the number of cultural trait frequencies is somewhat arbitrary, but it repre-

sents the balance between required detail and computational expense. As such, this is similar to the manner in which Rendine, Piazza, and Cavalli-Sforza (1986) have modeled gene frequencies in Neolithic Europe.

As a means of modeling culture, this approach is comparable to the manner in which Whiten et al. (1999) have characterized the culture of a modern-day ape population as being the sum total of the discrete socially learned traditions within that population, although in their case a tradition is either present or absent. It is an effective manner in which to model hominin culture as represented by stone tool technology as that is composed of numerous socially learned traits, which may exist independently of each other. For instance, the manufacture of an Acheulean biface might include the selection of a naturally shaped nodule, the production of a large flake blank, bifacial flaking, thinning, the imposition of a pointed, ovate, cleaver or other morphology, attention to symmetry, and/or completion by a tranchet blow. Several of these traits could be broken down into further components or actions, and all of these can be characterized as separate cultural traits that might exist independently of each other. Hence, the culture of either an individual or a population can be described by a particular array of cultural trait frequencies, and that array can be compared with that of another individual or population.

THE MATHEMATICAL MODEL

In Stepping Out, the culture of the population in grid box x, y corresponds to a series of cultural trait frequencies, denoted by

$$F_{x,y} = \{f_{x,y}^1, f_{x,y}^2, f_{x,y}^3, \dots, f_{x,y}^N\}. \quad (1)$$

F is an inherited characteristic, and when a population colonizes an adjacent grid box, the new population inherits the F set of values from the parent population. F is not constant with time, and cultural drift is represented in Stepping Out by equation (2):

$$F_{x,y}^{t+1} = \{f_{x,y}^1 \pm \varepsilon_1, f_{x,y}^2 \pm \varepsilon_2, \dots, f_{x,y}^N \pm \varepsilon_N\}, \quad (2)$$

where ε is a small, random value, with a maximum magnitude equal to the constant α ; F^{t+1} are the updated cultural trait frequencies (i.e., at time step $t + 1$). After colonization, both populations undergo cultural drift and the cultural trait frequencies will diverge with time.

Although Stepping Out divides space into discrete grid cells, cultural transmission may occur between adjacent grid cells. This is incorporated by assuming that the cultural trait frequencies of adjacent populations converge together through interbreeding. The implication of this setup is that populations separated from the main body of the species will diverge, while the main body maintains rather homogeneous cultural trait frequencies.

The interaction of neighboring populations is represented in the model as equation (3):

$$F_{X,Y} = F_{X,Y} + \beta \cdot (F_{X,Y} - F_A), \quad (3)$$

where F_A is the cultural trait frequency array of the adjacent population, and β is the magnitude of cultural frequency mixing and is set a priori.

In order to compare two biological populations, it is common to calculate the genetic distance between them (Cavalli-Sforza, Menozzi, and Piazza 1994). We adopt this approach for measuring two cultural populations, by calculating the Euclidean distance between their cultural trait frequency arrays—equation (4). While other techniques for calculating this measure exist, this method is both simple and sufficient for the present analysis.

$$D_E = \sqrt{\sum_{d=1}^{d=20} (f_{X,Y}^d - f_{REF}^d)^2} \quad (4)$$

In analyzing the output from the cultural transmission component of Stepping Out, our interest is in divisions in the geographic patterning of cultural trait frequencies. To reduce the subjective component of such analysis, we use cluster analysis techniques. The aim of cluster analysis is to allocate each cultural population (i.e., each grid square in Stepping Out with its own array of cultural trait frequencies) to a particular group, or cluster, the global distribution of which can

then be illustrated. These are equivalent to what Movius would have described as “cultural complexes.” To create the clusters, we use the cluster algorithm of Krishna and Murty (1999). This includes an automatic initialization of clusters, and the final solution is independent of the choice of initial clusters.

THE DEFAULT MODEL

In Stepping Out, climate variability is driven by benthic foraminifera data (Ocean Drilling Program core 677; Shackleton, Berger, and Peltier 1990) and uses vegetation patterns derived from a general circulation model, HadCM3 (see Hughes et al., 2007, for a more detailed discussion of the environmental model). The default setup of Stepping Out has been calibrated for an expansion of *H. erectus* out of Africa, reaching the Dmanisi site around 1.8 mya, and provides the best fit with hominin arrival dates at Old World sites (Hughes et al., 2007). In the default setup, *H. erectus* has poor colonization ability, with high probability of local extinction (P_{ext}), in Eurasian forest environments; this setup best simulates a “late” arrival in Europe, in agreement with the suggestion of Dennell (2003) and the evidence of Parfitt et al. (2005). The vegetation types and default values of P_{ext} are (1) tropical forest ($P_{\text{ext}} = 0.01$), (2) warm-temperate forest ($P_{\text{ext}} = 0.08$), (3) temperate forest ($P_{\text{ext}} = 0.08$), (4) boreal forest ($P_{\text{ext}} = 1.00$), (5) savannah and dry woodland ($P_{\text{ext}} = 0.01$), (6) grassland and dry shrubland ($P_{\text{ext}} = 0.01$), (7) desert ($P_{\text{ext}} = 1.00$), (8) tundra ($P_{\text{ext}} = 1.00$), and (9) land ice ($P_{\text{ext}} = 1.00$).

Running the default setup of Stepping Out with the cultural component generates maps of cultural trait frequencies, which are the basis for analyses using both Euclidean distances and cluster analysis. For analytical purposes, the Old World is divided into four regions roughly equivalent to Africa, Europe, eastern Asia, and western Asia (figure 12.2a); specific subregions are also defined to facilitate a time series analysis of population levels (figure 12.2b).

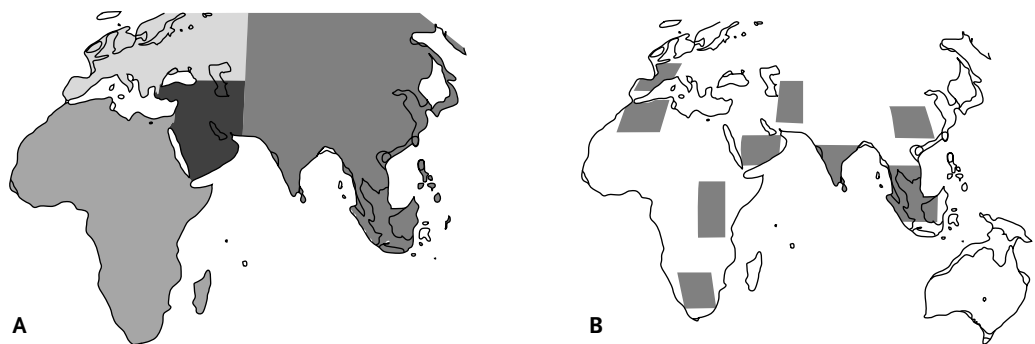


FIGURE 12.2 Maps of sites discussed in the text. Figure 12.2a (left) shows the divisions of land masses used to calculate cluster compositions. For simplicity, these four regions are referred to as Africa, western Asia, Europe, and eastern Asia (which includes Indonesia), though they do not correspond to present-day political boundaries. Figure 12.2b (right) shows the local regions over which population summaries are derived. Coastlines are shown for Pleistocene high and low sea levels.

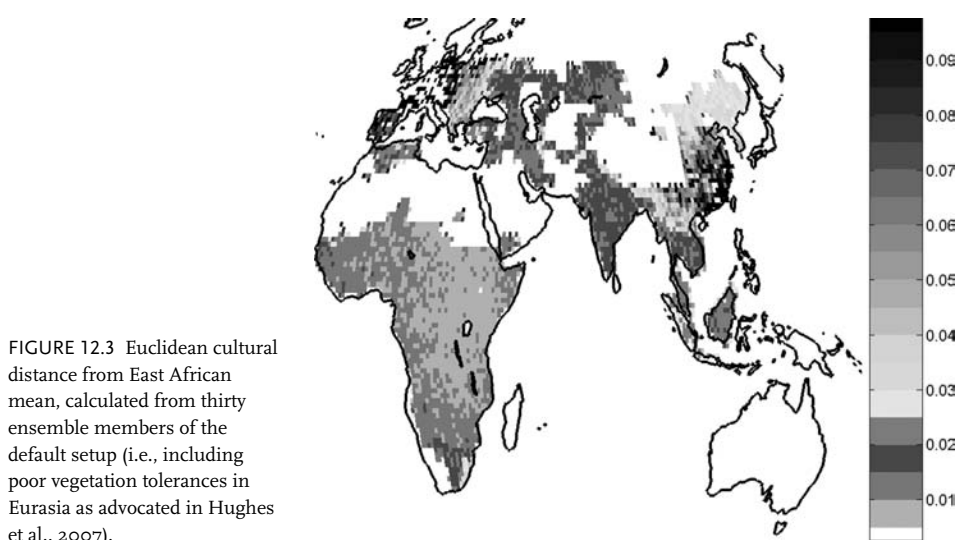


FIGURE 12.3 Euclidean cultural distance from East African mean, calculated from thirty ensemble members of the default setup (i.e., including poor vegetation tolerances in Eurasia as advocated in Hughes et al., 2007).

DEFAULT MODEL RESULTS

Stepping Out was run using the default setup for an ensemble of thirty simulations. Figure 12.3 shows a map of the resulting Euclidean distances of each occupied grid box, against an East African mean, combining all thirty ensemble members. This figure illustrates the cultural diversity present in the simulation and the degree of recurrent spatial patterning. Most noticeably, there is a gradient away from eastern Africa with some sharp transitions. Although physical distance is a key factor in the cultural divergence, this figure also suggests that various geographic features appear to act as bottlenecks, restricting the flow of hominin populations and cultural traits. There is restricted cultural trait flow

between African and Eurasian populations owing to the restricted possibilities for movement between these regions. Intriguingly, areas such as northern China and western Europe, less obviously isolated from adjacent populations, also appear sharply differentiated. This suggests that environmental variability and patterns of *H. erectus* movement in Stepping Out are also important and act to create bottlenecks in these regions.

The twenty simulated cultural frequencies, $\{f^1, f^2, f^3, \dots, f^{20}\}$, are decomposed into two clusters at the end point (1 mya) of each simulation. Twelve of the simulations cluster similarly to figure 12.4a, and seventeen of the simulations cluster similarly to figure 12.4b (thereby accounting

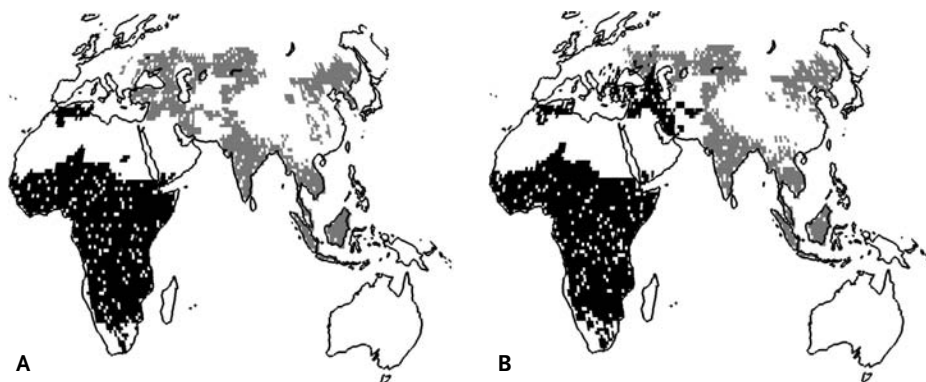


FIGURE 12.4 Examples of cluster analysis with the default setup of Stepping Out at 1.0 mya. Figure 12.4a (left) shows clustering typical for 12/30 simulations that demonstrate a dominant gray cluster in Eurasia. Figure 12.4b (right) clustering is typical of 17/30; in all seventeen cases, the African clustering of Eurasian culture is in the same region (Southwest Asia).

for the majority of simulations). These figures show that the primary division in cultural trait frequencies occurs between African and Asian populations. When all thirty cultural trait frequency maps are analyzed, the African cluster characterizes 100 percent of African populations (i.e., occupied grid squares, to the nearest 1 percent), 37 percent of European populations, and only 11 percent eastern Asian populations (table 12.2). The western Asian region has a very small population level (see later discussion), but 46 percent of existing populations in this region are clustered with the African cluster. These results support the impression created by figure 12.3 and suggest that there is a significant barrier, maintained in all model runs, to the flow of cultural traits between Africa and Asia, which creates strong cultural differences between African populations and the rest of the world. It is worthwhile reiterating that the cluster analysis does not assume any geographic patterning and that these patterns emerge purely from the cultural trait frequency values.

CULTURE AND POPULATION HISTORY

To better understand the processes that create the spatially coherent cultural patterning observed in figures 12.3 and 12.4, the population histories of several regions are compared (figure 12.5; locations defined in figure 12.2b). These

results are a consequence of environmental/vegetation type changes affecting the ability to survive or colonize a particular grid box (as discussed earlier) and the local timing of arrivals. In the default setup of Stepping Out, dispersal out of Africa occurs before an increase in aridity and the associated reduction in vegetation cover in the Sahara and Arabia region; this is seen as 75 percent occupation of the Arabian region prior to 1.8 mya and the collapse of *H. erectus* occupation afterward. The reduction in occupation after 1.8 mya is also seen in northern Africa, where the region of habitability reduces after 1.8 mya. Occupation of China and Europe is marginal throughout the simulations and is caused by the vegetation tolerances assumed in Stepping Out.

A key feature of these results is that there are significant differences between regions, in terms of the date of arrival, the rate of population expansion, and population-level stability. For example, while sub-Saharan populations (e.g., southern Africa) rapidly achieve at least 80 percent occupation, other regions—for example, those in Europe—show evidence of smaller (<5 percent) occupation, and their population levels also show more pronounced fluctuations. In terms of cultural traits, these results show that regions that were most sharply distinguished from Africa (figure 12.3) are also associated with lower, less stable population

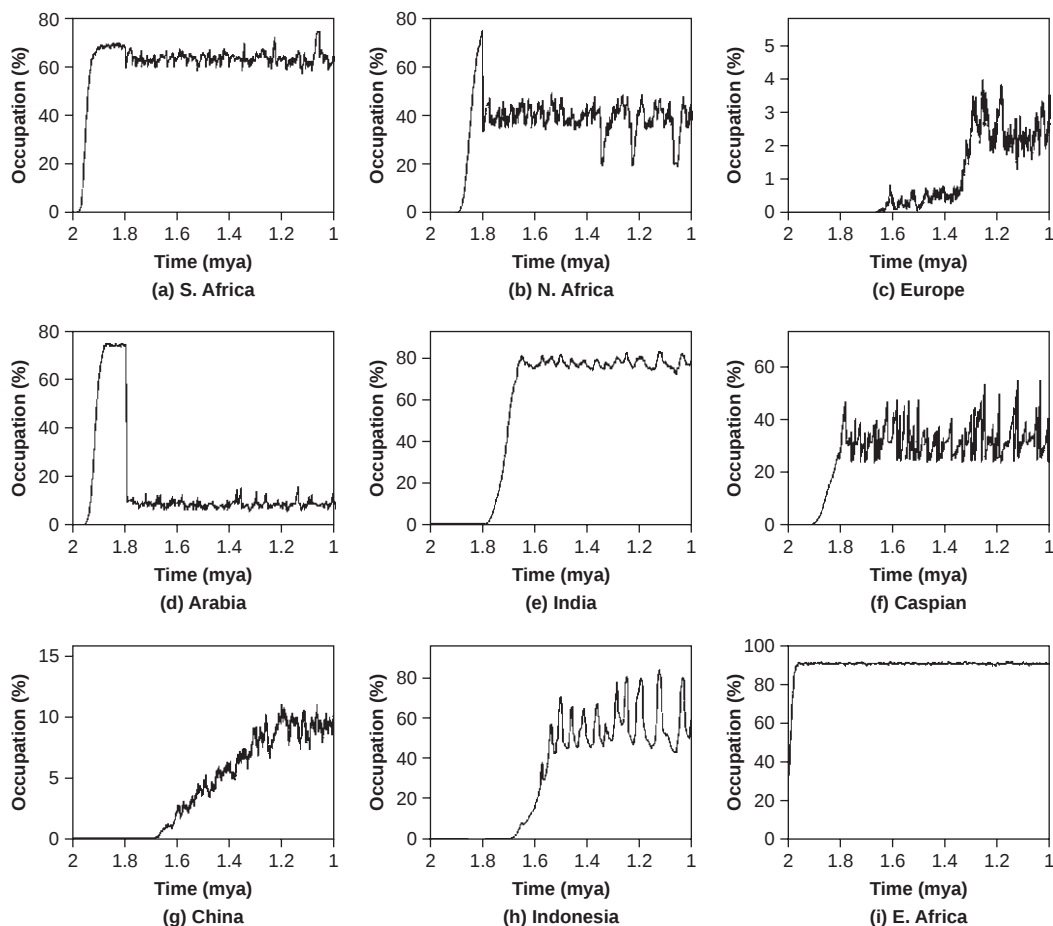


FIGURE 12.5 Time series of average occupation (as a percentage) of each region, from all thirty ensemble members (vertical axes differ).

levels. Significantly, these results are amenable to testing against archaeological and fossil data. The proposed nature of the earliest European populations, for example, fits well with the sparse, fragmentary archaeological and fossil record that has been suggested to characterize Europe during the Pleistocene (e.g., Dennell 2003; Parfitt et al. 2005).

The cultural trait frequencies from the various subregions are now considered. Figure 12.6 shows the Euclidean distance between cultural trait frequencies from each region and eastern African populations. The Palaeolithic cultures in southern Africa (figure 12.6a) maintain a small and stable distance from the eastern African cultures. Those in northern Africa (figure 12.6b) are separated after the transition to Pleistocene vegetation in the simulations and diverge from the

eastern African cultures over time. The cultures in Europe are marginal and also diverge away from the sub-Saharan African cultures (figure 12.6c). Arabia (figure 12.6d), India (figure 12.6e), the Caspian region (figure 12.6f), and Indonesia (figure 12.6h) all maintain a relatively stable Euclidean distance from the eastern African cultures, while the magnitude of this difference corresponds to the geographic separation (as seen in figure 12.2). The Chinese cultures (figure 12.6g) are highly variable and are among the most different from the eastern African populations; this difference increases with time.

In general, these data demonstrate that the regions with the lowest and most unstable population levels have both the greatest degree of cultural divergence from eastern Africa and also the highest level of variability between simulations.

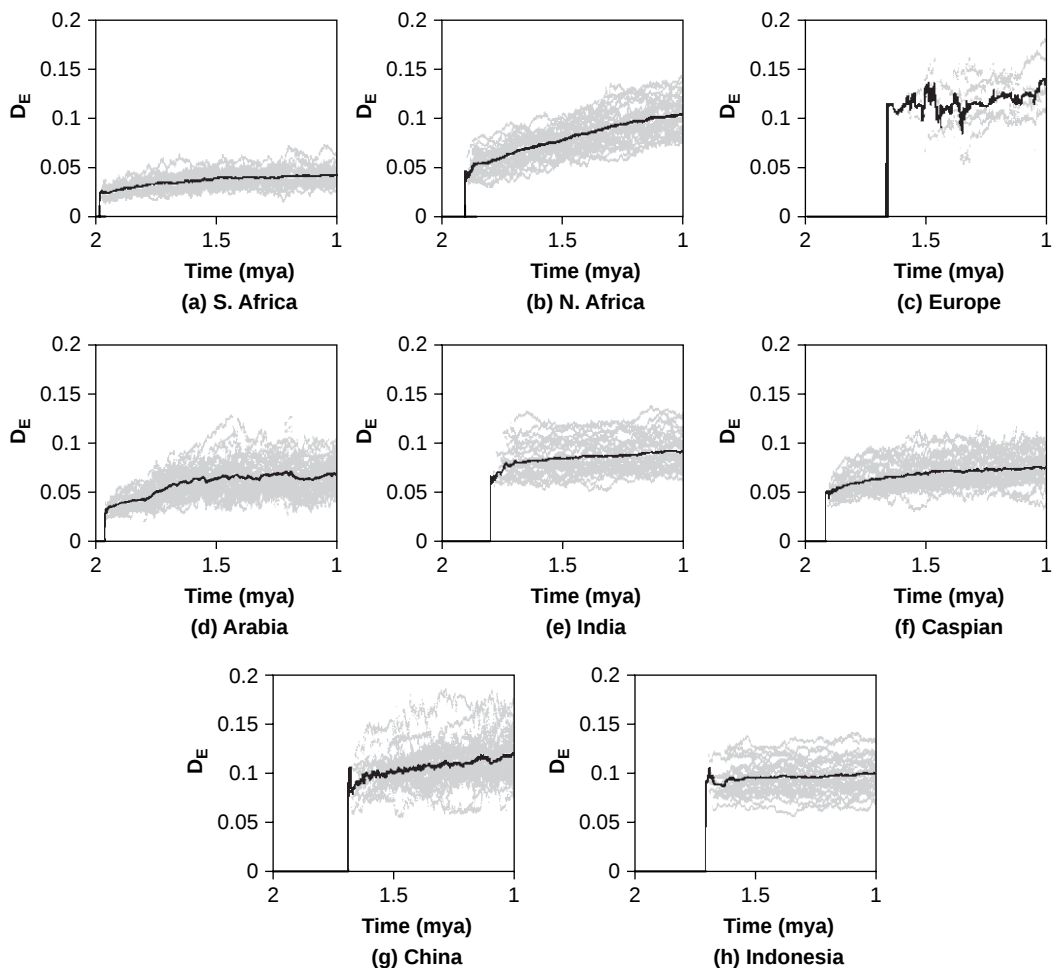


FIGURE 12.6 Trends in the Euclidean distance between a variety of regions and East African rift system cultural trait frequencies, for all thirty ensemble members of the default setup.

It is also significant that certain cultures, such as those from Indonesia, are quite distinct from those of Africa at the time of first arrival, but there is limited further divergence during the model run. This suggests that there is limited cultural transmission between Africa and Indonesia following the initial dispersal and stable occupation of Indonesia throughout the simulation. This result bears comparison with the archaeological record from Indonesia that shows long-term continuity of cultural traits, with pebble/flake industries in the Late Pleistocene and Holocene (Barstra 1982).

The additional analyses help to explain the observed patterning of African and Eurasian populations shown in figures 12.3 and 12.4. It is clear that in Stepping Out, cultural transmission

between groups is governed by the interplay of various factors including population level, physical distance, environment, and geography. This reinforces the need for a modeling framework such as Stepping Out that can integrate these factors over large temporal and geographic scales. In Stepping Out, it is clear that stable regional characteristics require continuous, extensive regional occupation and that these populations form a well-connected pool of cultural traits.

SIMULATION EXPERIMENTS TO EXAMINE THE ROBUSTNESS OF THIS RESULT

Figure 12.4 indicates that the most parsimonious assumptions about population dispersal and cultural transmission result in a barrier to

TABLE 12.1. *Experimental Setup for Each Simulation Discussed in This Chapter*

EXPERIMENT	VEGETATION SETUP	CROSSINGS (AFAR AND GIBRALTAR)	DRIFT STRENGTH	INTERBREEDING STRENGTH	COASTAL ROUTE	REPLACE NATIVE POP _N ?	RATIO CLIMATE: DISPERSAL
<i>default</i>	Poor	No	10 ⁻³	10 ⁻³	No	No	1:1
<i>drift</i>	Poor	No	10 ⁻⁴	10 ⁻³	No	No	1:1
<i>cultural mixing</i>	Poor	No	10 ⁻³	10 ⁻⁴	No	No	1:1
<i>non_native</i>	Poor	No	10 ⁻³	10 ⁻³	No	Yes	1:1
<i>coastal</i>	Poor	No	10 ⁻³	10 ⁻³	Yes	No	1:1
<i>veg_better</i>	Good	No	10 ⁻³	10 ⁻³	No	No	1:1
<i>no_desert</i>	No_desert	No	10 ⁻³	10 ⁻³	No	No	1:1
<i>uniform</i>	Uniform	No	10 ⁻³	10 ⁻³	No	No	1:1
<i>crossings</i>	Poor	Both	10 ⁻³	10 ⁻³	No	No	1:1

NOTE: The vegetation tolerances are defined in the model description section.

TABLE 12.2. *The Regional Importance of the African Cluster for a Range of Experiments, Derived from Thirty Simulation Ensembles*

EXPERIMENT	EUROPE	AFRICA	EASTERN ASIA	WESTERN ASIA
<i>default</i>	37	100	11	46
<i>drift</i>	35	100	15	38
<i>cultural mixing</i>	36	85	21	46
<i>non_native</i>	41	100	11	41
<i>coastal</i>	98	100	35	97
<i>veg_better</i>	40	100	8	47
<i>no_desert</i>	50	99	8	58
<i>uniform</i>	75	98	9	69
<i>crossings</i>	48	99	18	55

NOTE: See figure 12.2a for a definition of these regions.

the flow of culture traits from Africa into Asia and Europe. It is conceivable, however, that this might arise from the particular suite of parameter values used in the default setup of Stepping Out. To test this, a series of sensitivity experiments were performed in which one or more model parameters were changed. These experiments (table 12.1) changed the parameters controlling either the dispersal or cultural transmission process. The results from each experiment, in terms of the regional importance of the African culture cluster/complex, are listed in table 12.2.

The importance of cultural drift and cultural mixing are tested in two experiments, *drift* and *cultural mixing*, which reduce the parameters controlling these to 10 percent of the default val-

ues. When the rate of cultural drift is reduced, the Euclidean distance (against eastern African *H. erectus*) of each region is also reduced (to approximately 10 percent that of the default setup). However, the Africa/Eurasia division remains, the African cluster is still associated with 100 percent of the populations in Africa, while the Eurasian populations are also basically unchanged (table 12.2). This insensitivity is not seen when the strength of cultural mixing is reduced to 10 percent of the default value. This results in cultural mixing being unable to counterbalance the effects of cultural trait frequency drift; African *H. erectus*, for example, do not behave as a strongly coherent cultural complex. Figure 12.7 shows two examples of cluster distributions from the *cultural mixing* experiment. In this experiment

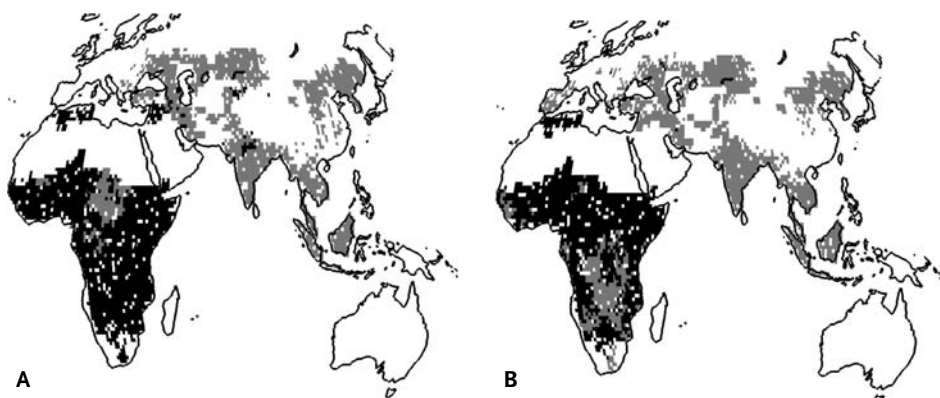


FIGURE 12.7 Examples of cluster analysis with the low cultural mixing experiment at 1.0 mya.

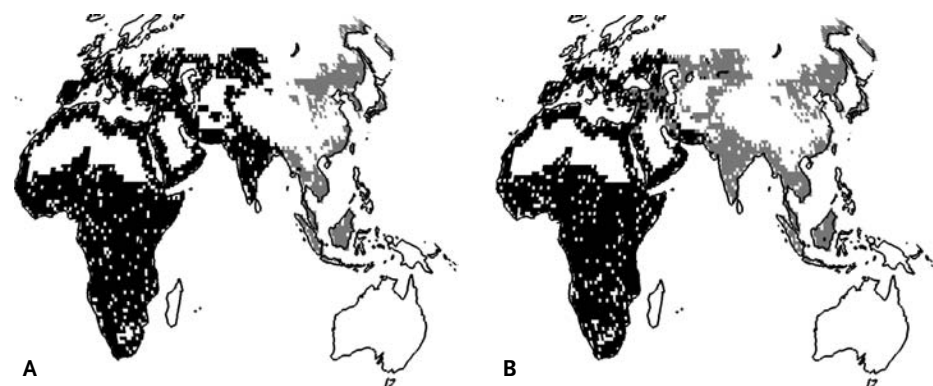


FIGURE 12.8 Examples of cluster analysis with coastal adaptation experiment at 1.0 mya. Both figures 12.8a and 12.8b are typical of 11/30 ensemble members.

the African/Eurasian dipole remains but is weakened, and only 85 percent of African populations are clustered in the African cluster (table 12.2).

Another sensitivity experiment, *non_native*, inverted the rule of competition so that colonizing populations always replaced a native population. One might expect this to result in greater cultural mobility, which would reduce the African/Eurasian dipole. The clustering resulting from this experiment, however, is within 5 percent of the default experiment values. This suggests that the interaction between resident and colonizing groups is not a significant factor in the formation of regional cultural patterning, presumably since populations are replaced by nearby populations with similar cultural signatures.

The cultural implications of altering the colonization abilities of *H. erectus* are examined in a series of further experiments with *Stepping Out*. The *coastal* experiment enhances the survival rate of *H. erectus* in grid boxes adjacent to the coastline (i.e., a coastal adaptation). Populations within these boxes are given a reduced probability of local extinction, equal to the value used in the savannah environment ($P_{\text{ext}} = 0.01$). The result is an increase in the cultural trait flow between *H. erectus* populations from different regions, leading to the cluster distribution shown in figure 12.8. The continuous route that is now open from Africa to Europe and western Asia results in the dominance of the African cluster in these regions (98 percent and 97 percent, respectively; table 12.2). In addition, 35 percent of the Asian

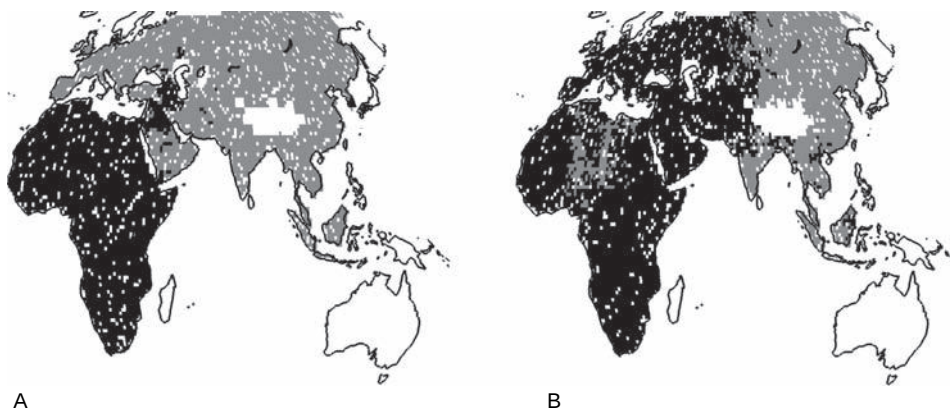


FIGURE 12.9 Examples of cluster analysis for the uniform experiment (ignoring the influence of vegetation) at 1.0 mya.

hominin populations are now allocated to the African cluster, which is the largest value for any of the experiments. Significantly, as shown in figure 12.8a, the majority of Asian populations assigned to the African cluster are located in India, while Southeast Asian populations remain culturally distinct.

Hughes et al. (2007) showed that the chronology of early Eurasian hominin sites is consistent with poor environmental colonization ability, although with the limited data available for much of Eurasia, this issue must remain contentious. Stepping Out was therefore run with improved colonization abilities in the experiments *veg_better* and *uniform*. The *veg_better* experiment increased survival of *H. erectus* in the Eurasian landscape (changing P_{ext} values for warm temperate and temperate forest from 0.08 to 0.03). The *uniform* experiment replaces the local extinction probabilities for all vegetation types, other than tundra and ice, with the value for savannah (0.01). In these experiments, particularly the *uniform* experiment, Eurasian populations are larger and more stable than under default conditions (figure 12.9). In terms of cultural patterning, both experiments act to increase the division between Africa and Asia. In Europe, however, the increased population acts to enhance gene flow with African populations (particularly in the uniform experiment). It thus appears that a larger and more stable European population lead this region to be more

culturally connected to Africa. It should be noted, however, that Europe is the region most sensitive to parameter changes, probably as a result of the sparse and fluctuating population in this region under the default setup.

To explore the role of the desert as a biogeographic barrier, the *no_desert* experiment uses the default vegetation tolerances, but with the desert value of P_{ext} changed from 1.00 to 0.01. This dilutes the cultural clustering in Africa to 99 percent but otherwise has a limited effect. This is a rather unexpected result given the significance of deserts in affecting regional population levels demonstrated in figure 12.5.

A further experiment examined the effect of increasing the ability of *H. erectus* groups to make short sea crossings, either by natural or deliberately manufactured rafts. This experiment is of particular relevance in light of the evident sea crossing made by those hominins that reached Flores island by 0.8 mya. To this end, the *crossings* experiment permits *H. erectus* to cross both the Straits of Gibraltar and Bab el Mendebe into southern Arabia. The result is, not surprisingly, to increase the connection between Africa and both Asia and Europe relative to the default setup (table 12.2), further emphasizing the importance of behavior and adaptation in governing contact and culture flow between populations.

The additional experiments have allowed us to examine the causes of the cultural patterning

observed in the default setup; moreover, they demonstrate the potential of Stepping Out to evaluate hypotheses at both global and more local scales of analysis. For example, these simulations suggest that the influence of desert barriers is less significant than might be anticipated, while including a coastally adapted hominin dramatically alters the default cultural patterning. In general, the Africa/Asia split is very robust to parameter changes and is largely dependent on the existence of a large and well-connected African population, with the flow of populations into Eurasia limited by distance and geographic bottlenecks, leading to the establishment of a stable secondary population in Southeastern Asia.

CONCLUSION

Previous studies have shown that Stepping Out is a valid model for hominin dispersal from Africa as it can replicate the timing of arrivals at specific localities (Mithen and Reed 2002) and the population history of particular regions in the Old World (Hughes et al., 2007). It is a model that integrates the latest models for global climate and palaeoenvironmental change during the Pleistocene with parsimonious assumptions for the processes of hominin dispersal. As such, it enables one to explore the impact that biogeography and different models for hominin behavior would have had on the patterns of hominin dispersal and consequently on the fossil and archaeological record.

In this version of Stepping Out, we have added a process of cultural transmission. We have described a population's (i.e., an occupied grid square's) culture as an array of values for twenty cultural traits, conceiving this as a valid model for their knowledge and traditions about making stone tools in which each socially learned action or preference can be characterized as a single trait. We have then modeled the processes of cultural drift and cultural mixing (but not selection) and used cluster analysis to create two cultural complexes for the Old World. As such, we have integrated a simulation for hominin dispersal with one of cultural

transmission to explore global patterning in stone tool technology.

The key result is a robust demarcation between an African and a Eurasian cultural complex, one that persists throughout the majority of the simulation experiments. In other words, although hominin populations disperse from Africa into Europe and Asia, there is a limited flow of cultural traits from Africa into these regions. In approximately half of the simulation runs, this African cultural complex was restricted to Africa; in the other half of the runs, it included western Asia (figure 12.4). Consequently, if we assume that the stone tool culture of the earliest hominins in Stepping Out, those dispersing from Africa 2 mya, was a pebble/flake industry, then any new developments in Africa will not spread to those populations that become resident in Europe and Asia. This is precisely the pattern that we observe in the archaeological record: while the Acheulean appears in Africa by 1.6 mya, it remains absent from Europe until 0.5 mya and may never spread to Southeast Asia, where pebble/flake industries persist. The dating of the earliest Acheulean in India remains unclear; similarly, it is unclear whether, as in Europe, this is preceded by a pebble and flake industry. Our model suggests that there is a pebble/flake industry in the region and that the Acheulean is relatively late, with its origins broadly contemporaneous with the European Acheulean. Resolution of these issues is hampered by a lack of data regarding the origins of the Indian Acheulean, although initial assays, which indicate a middle-late Pleistocene date for these assemblages (Petraglia, Shipton, and Paddayya 2005), appear to support the model results.

While uncertainty surrounds some of the archaeological data, the Stepping Out model appears able to replicate the Movius line without the need to invoke factors such as an absence of suitable stone for making bifaces, the presence of alternative raw materials, different functional needs, or the loss of knowledge about biface manufacture. In other words, the Movius line can be explained as a consequence

of geographic and ecological factors that constrain patterns of hominin movement and the flow of cultural traits.

There are, of course, numerous caveats to this conclusion as it is dependent on the reliability of the assumptions and the structure and parameters of the Stepping Out model. One key feature of the current model is the absence of cultural selection: it is assumed that one array of cultural trait values is as functionally useful as any other, and these thus do not influence the probability of hominin survival and colonization. This might be questioned with regard to Acheulean technology: hominins with bifaces may have had enhanced reproductive success over those with flake tools owing to their functional advantages for butchery (Mitchell 1996) and for mate attraction (Kohn and Mithen 1999). Whether hand axes do provide such functional advantages remains unclear, and one must also take into account the time taken to acquire technical skills to manufacture bifaces (Porr 2005) when making such assessments. Nevertheless, the introduction of cultural selection for particular cultural trait arrays would be a valuable further development of Stepping Out.

This pattern of a distinct African and a Eurasian cultural complex that arises in the absence of cultural selection persists throughout the majority of the simulation experiments within the current study. The experiment that had most impact on this pattern was *coast*, which enhanced the survival rate of hominins in coastal regions. Mithen and Reed (2002) had previously shown this to have a significant influence over dispersal patterns; we have now shown that it also has a significant influence on the global pattern of hominin culture. By enhancing the ability of hominins to survive in coastal regions, Europe becomes part of the African cultural complex. In some instances, India also becomes part of this complex, while Southeast Asia always remains culturally distinct. The simulated pattern of cultural diversity in figure 12.8a, which matches eleven out of thirty of the *coast* runs, has a striking

resemblance to the archaeologically observed pattern of cultural diversity in figure 12.1.

To conclude, we propose that global patterning in Lower Palaeolithic stone tool technology can be explained by reference to the geographic and palaeoenvironmental opportunities and constraints on the process of hominin dispersal and cultural transmission. The earliest hominin dispersals from Africa were associated with a pebble/flake culture that became established in Europe and Asia; when the Acheulean was invented/discovered in East Africa about 1.6 mya, this would have spread throughout Africa and possibly into western Asia, but not into Europe or southern Asia. At 0.5 mya, the colonizing abilities of hominins in coastal regions became enhanced (possibly related to the appearance of *Homo heidelbergensis*), which resulted in the African cultural complex—which by that date was Acheulean in character—spreading to Europe. That of Southeast Asia remained unchanged as a pebble/flake culture.

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THIRTEEN

Population History and the Evolution of Mesolithic Arrowhead Technology in South Scandinavia

Kevan Edinborough

THEORIES OF cultural evolution have developed rapidly in recent years, but the number of archaeological case studies that make use of these ideas to develop and test hypotheses remains small. This chapter addresses the specific evolutionary mechanisms affecting technological stability and change in projectile point technology in data-rich Mesolithic southern Scandinavia, with a case study focusing on Zealand and westernmost Scania.

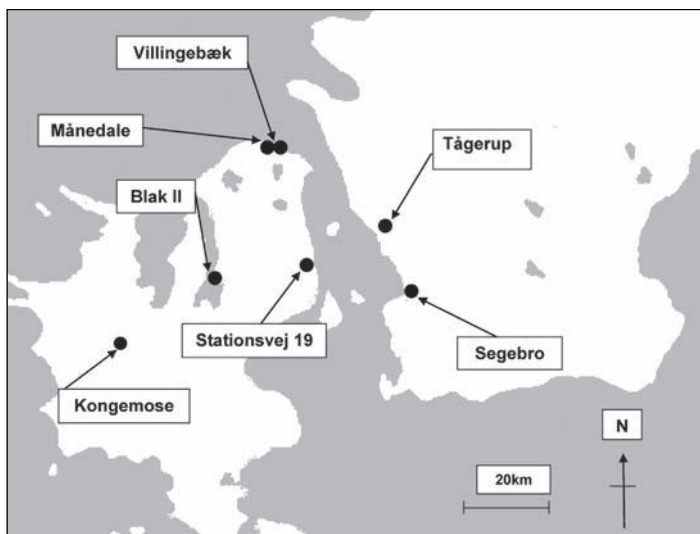
An extensive regional database of archaeological data was collated from seven previously excavated Middle–Late Mesolithic southern Scandinavian archaeological sites dating from about 6500–4600 BCE (Edinborough 2004). A chronological model was created for the nine archaeological site phases represented, using all available stratified ¹⁴C results. Variation between projectile points found in these site phases was then characterized in terms of the lithic technology used to produce them, using some key point dimensions. Two hypotheses were then considered as possible explanations of the observed patterns. First, the possibility

that the changes could be accounted for as a result of changing prey priorities was investigated by carrying out a correspondence analysis of osteological count data from four archaeological phases spanning the entire duration of the case study. Second, it was postulated that the technological patterns could be accounted for in light of various models of the effect of variation in population size on the transmission of cultural traditions. For this purpose, a model of regional population history was constructed using all available radiometric data. Evidence of fluctuating population sizes through time was then correlated with the evidence of stability and change in projectile points.

CASE STUDY BACKGROUND

From about 14,000 BCE, the final Pleistocene in northern Europe is characterized as a period of continuous warming from the Late Glacial Interstadial, only interrupted by the Younger

FIGURE 13.1 Nine case study site phases on the easternmost Danish island of Sjælland (Zealand) and the southwestern Swedish region of Skåne (Scania). Note Tågerup contains three key archaeological phases, termed here Tågerup Kongemose, SU7, and Tågerup Ertebølle.



Dryas Stadial. The land was covered by ice sheets until the end of the Devensian/Weichselian at around 12,000–11,000 BCE, when the sea level was nearly 60 meters lower than today. After complex localized changes, by about 3000 BCE, many coastlines were generally higher and further inland than today. As mean temperature rose swiftly, southern Scandinavia emerged from the arctic tundra through a complicated process of eustatic sea level rise coupled with isostatic land rise, which varied dramatically according to different geologic factors and still continues in certain Scandinavian locales (Price 1991, 215).

Highly diverse and rich environments emerged in the wake of the retreating ice, with new coastlines, lakes, marshes, and forested environments allowing a plethora of new species to colonize them. In very general environmental terms, after the ice, northern Europe was colonized by grassy steppe tundra with dwarfed birch and willow, then open birch forests, followed by mixed birch–pine forest with other species such as ash, aspen, and elm, as disclosed by pollen analyses (Birks 1981; Huntley and Birks 1983; Price 1991, 214; Karsten and Knarrström 2003, 22). The Scandinavian Boreal pollen zone (ca. 7000–6000 BCE)

period was characterized by the appearance of hazel–pine forest; temperatures became similar to today. As the arctic tree line moved northward, elm declined probably through disease, and the case study period in question was warmer than today (mean annual temperature about 2.5°C higher than present). Rapid sea level rises had dramatic affects on long-term human settlement patterns as many Danish and Swedish Mesolithic coastal settlements are now underwater (Sørensen 1996; Skaarup and Grøn 2004), while new inland environments allowed different resources to be exploited by local and perhaps nonlocal populations (Larsson 1983; Sørensen 1996; Karsten and Knarrström 2001). Ameliorating climate was probably favorable to hunter-gatherer groups. Recent archaeological settlement size evidence suggests larger sedentary groups were more likely the norm for the late Pleistocene and early Holocene, rather than the smaller mobile groups that rough ethnographic comparisons have predicted (see Price 1991, 211; Karsten and Knarrström 2001, 2003).

Faunal evidence suggests that cold-adapted species, notably reindeer, were confined to higher elevations of Scandinavia, while new

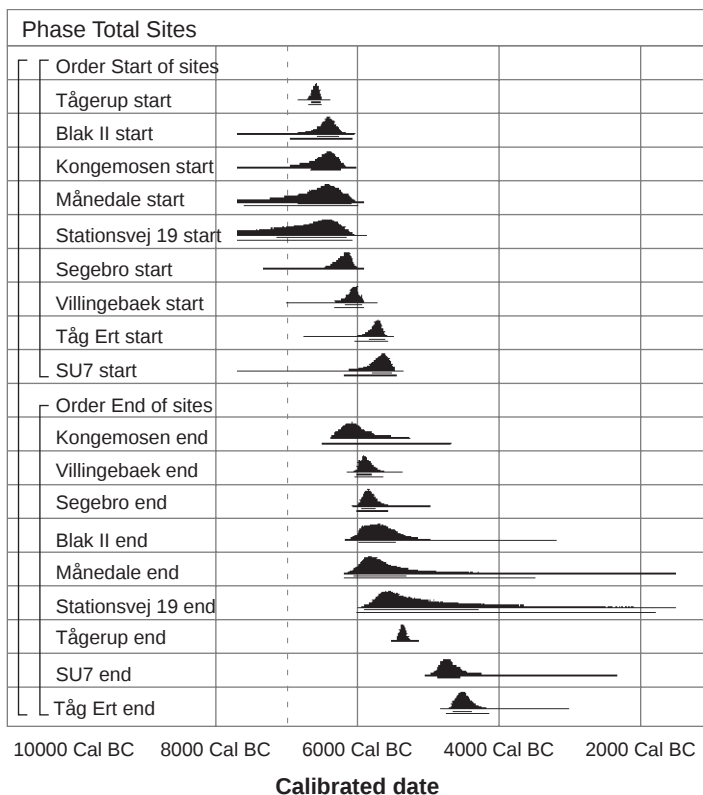


FIGURE 13.2 Start and end of each phase.

local species precipitated an economic shift from exploitation of aurochs and elk, to red deer, wild pig, and roe deer. An abundance of fish, fowl, sea mammals, and small fur-bearing mammals also flourished and were exploited at this time. Predators such as wolves could be seen as occupying a very similar ecological niche to humans and were probably in competition for very similar resources. Perhaps as a result of environmental niche proximity between scavenging wolves and humans, dogs were domesticated early and were likely to have formed a key part of contemporaneous hunting strategies, either through baying or tracking in association with bow hunting (Karsten and Knarrström 2003, 59).

CASE STUDY DATA

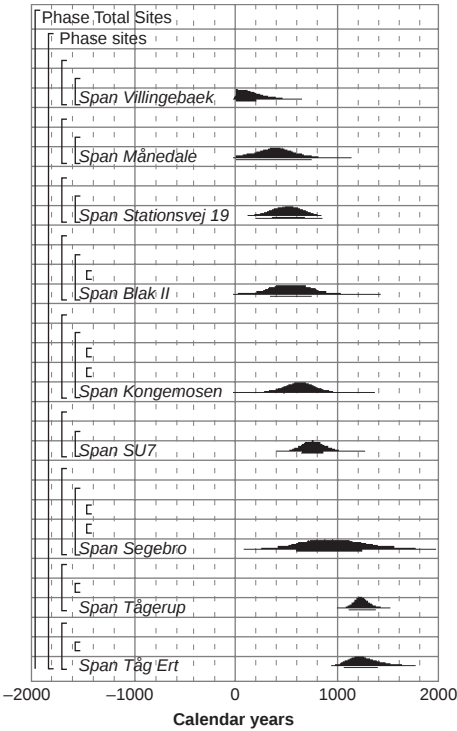
The nine site phases selected for the case study (see map, figure 13.1) contained a combined total of about 3,600 complete lithic armatures from

the southern Scandinavia middle Mesolithic, from circa 6500 to 4600 BCE (Sørensen 1996; Vang Petersen 1979, 1984).

The Danish lithic points used here from all sites except Stationsvej 19 have already been classified as arrowheads by Vang Petersen (1979, 1984), whose extensive analysis and frequency seriation facilitated the construction of the predominant Scandinavian typology for the Middle and Final Mesolithic. All Stationsvej 19 arrowheads have been identified as such by Brinch Petersen (personal communication). All the projectile points used in the case study analysis come from sealed deposits, with ^{14}C results available from associated stratigraphy, and can be mapped to individual grid references of excavated meter squares.

Osteological data exist for each of the sites used here; however, much of the Danish evidence remains at the zoological museum in Copenhagen awaiting analysis. As such, four key site phases from Skåne (Scania) in

FIGURE 13.3 Duration of each phase.



southwestern Sweden provide the osteological data for this case study, as they cover the entire time period of all combined phases, and osteological evidence indicates year-round site occupation (Larsson 1982; Mårtensson 1999; Karsten and Knarrström 2003).

CASE STUDY CHRONOLOGY

The Middle Mesolithic period in southern Scandinavia has the earliest known stratified projectile point evidence with statistically significant sample sizes that could be securely ordered using absolute dates. Raw ¹⁴C results were taken from the following reports: Brinch Petersen (1973), Karsten and Knarrström (2001), Larsson (1982), and Sørensen (1996). There are over two hundred ¹⁴C results available from the traditionally termed Kongemosen and associated Late Maglemosen sites (Sørensen 1996, 172–176), although the 102 dates finally used to generate figures 13.2 and 13.3 are unevenly distributed across the case study sites (table 13.1).

A chronological model for the case study was constructed with the OxCal calibration program modeling facilities, using audited radio-carbon data to determine the start, end, order, and duration of each find-bearing phase; see figures 13.2 and 13.3 (Bronk Ramsey 2005; calibrated using the IntCal 2004 calibration curve, Reimer et al. 2004). In general terms, the results demonstrate a cluster of six Kongemose phases, bracketed by the Blak phase earlier, and the SU6 and Tag Ertebølle phase later. The Tågerup phase was remarkably long, circa 1200 years, while the Villingebæk phase (top of figure 13.3) was very brief indeed.

TABLE 13.1. Approximate Chronology of the Case Study Period

CULTURE	STARTING POINT
Ertebølle	ca. 5500 BCE
Kongemose	ca. 6400 BCE
Maglemose	ca. 8900 BCE

NOTE: Dates adapted from Vang Petersen (1999, 10).

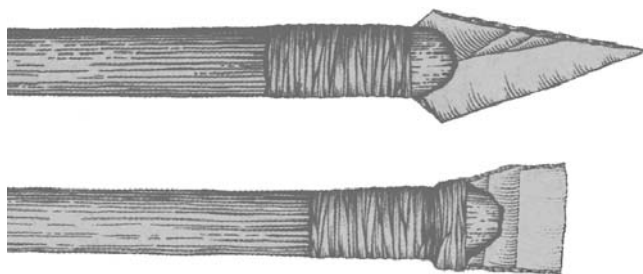


FIGURE 13.4 Case study arrowhead hafting as hypothesized for oblique arrowheads (above) and transverse arrowhead (below), not to scale (following Larsson 1982).

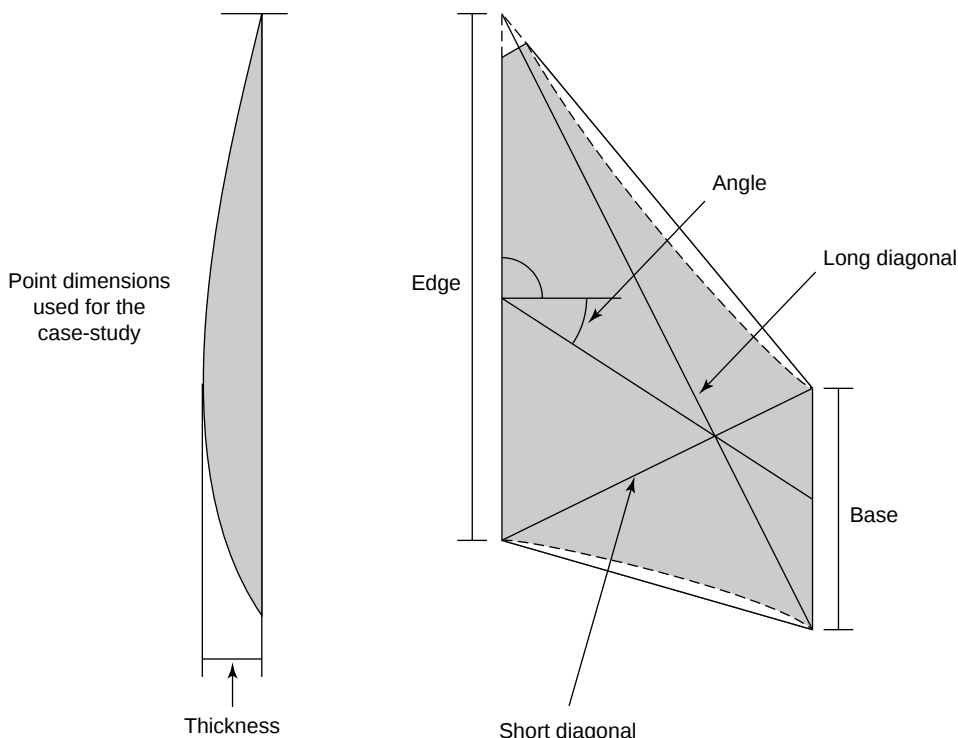


FIGURE 13.5 Seven dimensions including weight were used in the case study analysis. Photographs are not to scale.

ARROWHEAD TECHNOLOGY

Over 3,600 microliths classified as arrowheads were measured during the summer of 2002 (Edinburgh 2004, 2005; figures 13.4 and 13.5). Thirty points were then randomly selected from each of the nine archaeological phase assemblages, giving a total sample size of 270. The projectile points used in this study are thought by the excavators to originate from two main types of blade technology. The first was that of indirect percussion using a punch blade tool, often with an associated complex microburin technique to shape the individual projectiles,

resulting in blades and subsequently microliths of a highly consistent maximum thickness. This technique is strongly associated with technology attributed to the Kongemose culture. The second blade technology, less complex to manufacture, is termed a hard hammer direct percussion technique, used to detach blades from a core, resulting in generally thicker blades, with characteristically less standardized microliths. This technology is strongly associated with the Late Mesolithic Ertebølle cultures.

Certain key characteristics were seen as indicative of the degree of 'transverseness' of a

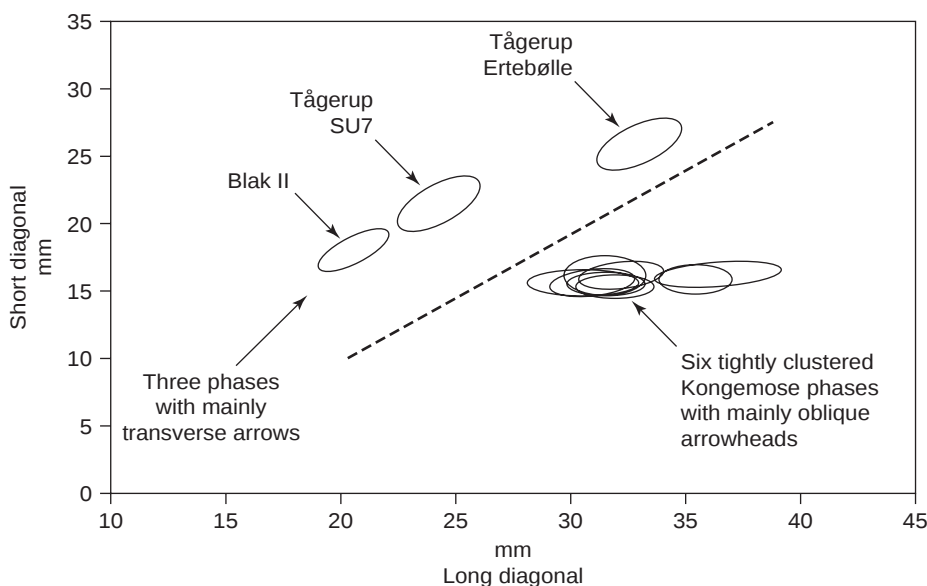


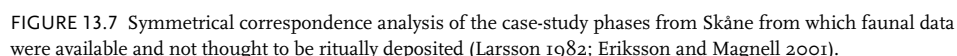
FIGURE 13.6 N points = 270, with 30 points per phase. Ninety percent mean confidence ellipsoids are shown using software constructed by Bill Grimm. Notice the chronologically early Blak II assemblage that predates the main six-phase cluster using the complex indirect-punch blade technology. Tågerup SU7 and SU6 phases, which have larger, less constrained ellipses, use direct hammer lithic technology.

given arrowhead. Vang Petersen's exhaustive typological/seriation method relies on the correct identification of the hafting orientation of each arrowhead. A functional use wear study by Knarrström (2001; Karsten and Knarrström 2003) determined that rhombic arrowheads from the earliest Blak phases of the Scanian Tågerup excavations were not obliquely hafted. After extensive multivariate statistical analysis, it was found that variation in the case study point assemblages was best characterized simply by plotting the long against the short diagonal dimensions (see figure 13.6).

The chronological results (figures 13.2 and 13.3) demonstrate that the six tightly clustered Kongemose site phases are temporally bracketed by the other three phases. Blak II predates the main cluster, although it is probably contemporaneous with the earliest phase of Tågerup Kongemose. Tågerup SU7 and Tågerup Ertebølle postdate the main cluster of six phases. The results of the statistical analyses are summarized here by the contrasting orientation of the two groups of ellipsoids separated by the dotted line

(figure 13.6), supporting the view that Blak II, Tågerup SU7, and Tågerup Ertebølle phases employed mainly transversely hafted arrows. It appears probable that a technological change coincided with the start of the tightly clustered group of six (Kongemose phase) sites that had obliquely mounted hafting traditions.

The phase duration and homogeneity of complex indirect-punch arrowhead technology during the six Kongemose phase assemblages indicates a long-term sphere of social interaction between the six clustered site phases, with a common technological tradition that lasts in excess of a thousand years—almost 1,200 years in the case of Tågerup in Skåne. Note that the Blak II phase arrowheads are likely to have been transversely hafted, while being manufactured using punched blade technique. It appears that this more complex blade technology, developed over a lengthy period during the Maglemose, largely disappeared by the Early Ertebølle phase. It now remains to place these technological changes into their environmental and ecological context to see if any external factors may have caused them.



As noted, it seemed possible that the changes in point morphology and/or lithic reduction strategy might be related to changes in prey type, which would be reflected in the available faunal data. The technique used for analyzing faunal data here is correspondence analysis (CA). Figure 13.7 shows the results of a symmetrical correspondence analysis for mammalian data for the four Scanian site phases used in the case study (cf. Blankholm 1994). Table 13.2 shows that the sites are probably in sequential chronological order of initial occupation (A–D), despite an extensive temporal overlap due to their relatively long

In terms of projectile shape, SU7 is much closer to Tågerup Ertebølle in terms of common point morphological characteristics (see figure 13.6) than it is to Tågerup, with which it shares its faunal pattern. The centrality of large ungulates on the CA axes indicates a constant emphasis through time and phase on these resources despite changing arrowhead morphologies. This

SITE	A. TÅGERUP	B. SEGEBRO	C. SU ⁷	D. TÅG ERT
Phase dates (calBCE)	ca. 6500–5400	ca. 6200–5800	ca. 5600–4800	ca. 5600–4600
Phase duration (years)	ca. 1200	ca. 400	ca. 800	ca. 1000

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view is reinforced by comparison of the absolute proportions of the faunal data (Edinburgh 2004, chap. 6). The diversity of other prey types shown by the CA probably relates to the fauna most readily available in the individual site niches.

According to Friis-Hansen's (1990) work on constructing a relative effectiveness index (termed the Cutting Index, or CI) for Mesolithic arrowheads in terms of performance related to different arrowhead morphologies, the central six-phase Kongemose group's oblique cutting arrowheads (figure 13.6) are likely to be near the engineering optimum for hunting large ungulates, in contrast to the value calculated for transverse arrowheads. Given the continuing centrality of large ungulates in the local diet, alongside other less economically significant niche-specific prey types, changes to point shape are apparently not the result of directional selection. Functional adaptation is effectively eliminated as the mechanism directly responsible for variation in the case study arrowhead morphology.

POPULATION HISTORY AND TECHNOLOGICAL CHANGE

We can now turn to the second possible explanation for changing technology considered here, that it is connected in some way with fluctuations in population size. For example, Henrich's recent study used qualitative Tasmanian data to argue that a drop in the effective population size (the size of the interacting pool of social learners) caused by rising Holocene sea levels resulted in a loss of complex technologies (Henrich 2004, 197). Henrich proposed that a reduction in teachers/learners generated maladaptive losses in more complex technological knowledge concerning fishing, while some simpler lithic technologies actually became more complex, as the sea levels rose around Tasmania. Although convincing in his formal modeling and general level of explanation, Henrich did not explicitly link any data for population levels to empirical details of technological change; the

supporting archaeological evidence was only described in broad qualitative terms.

In this study, human population fluctuations were modeled for the case study region and chronological period (figure 13.8). The method used here combines the available calibrated ^{14}C data into a plot that is then taken as a proxy for demographic fluctuations through time (see Gkiasta et al. 2003; Gamble et al. 2004, 2005). Three hundred fourteen ^{14}C distributions were input from 89 archaeological phases in Denmark and southern Sweden spanning the Maglemose, Kongemose and Ertebølle periods. The raw data was entered into CalPal (Weninger, Jöris, and Danzeglocke 2005), and a probability distribution curve was calculated.

For the southern Scandinavian data (figure 13.8, upper plot), a refined population proxy model was developed, where each archaeological phase containing published ^{14}C dates throughout the southern Scandinavian Mesolithic ($n = 314$ dates) was time-averaged using the OxCal program's R_Combine function. The R_Combine command produced a single pooled-mean date for each site's occupation horizon taken as the most parsimonious date for the occupation of each phase. Each of these time-averaged phase dates were then combined using CalPal, to produce a time-averaged probability distribution. This final distribution is used here in the upper plot to represent fluctuating population in calendar years. The advantage with this method is that sites such as Tågerup with multiple radiometric results are less likely to skew the results.

The results require cross-referencing with the more chronologically accurate Bayesian nine occupation phase model (figures 13.2 and 13.3). The period around 6000–5700 BCE (figure 13.8) shows a drop in proxy population and a loss of complex (Maglemose/Kongemose) arrowhead manufacturing technology. A loss of complex earlier arrowhead manufacturing technology, with a corresponding adoption and fixation of a less complex arrowhead technology, is more likely at this time of probable low

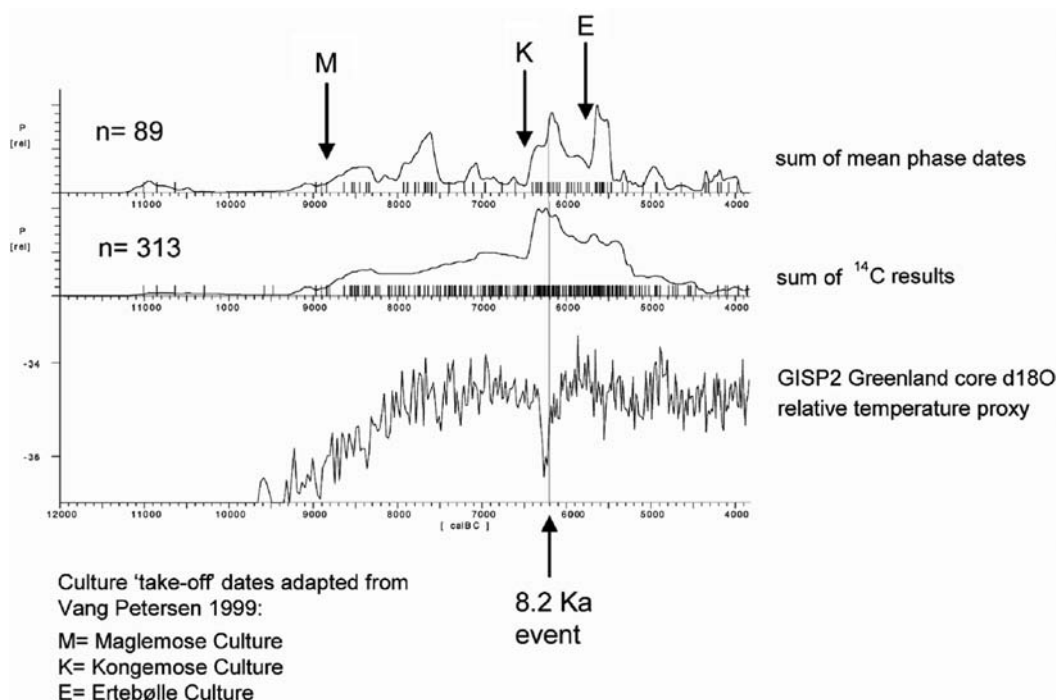


FIGURE 13.8 CalPal Plot showing the results of two "radiocarbon dates as population" models, in relation to the global and abrupt climate cooling event of 8.2 kya (Alley and Ágústssdóttir 2005). The central population-proxy plot used a CalPal sum of all available radiometric data for southern Scandinavia. The upper population proxy plot was generated by summing in CalPal the average date for each of the eighty-nine archaeological phases using the OxCal R_Combine function. This pooled-mean date method eliminates sample size bias from phases with multiple ¹⁴C samples. If this graph indeed represents relative population sizes during the case study period, the take-off of the Kongemose Culture (K) appears unaffected by the 8.2 kya event.

population density, whether purely through chance (cf. Neiman 1995) or as a result of the sort of process described by Henrich (2004). The Swedish radiometric data presented earlier suggest this technological loss happens slightly earlier than in Denmark. The start date of the Tägerup SU7 and Tägerup Ertebølle phases co-occur with the switch to predominantly less complex direct hammer percussion arrowheads (table 13.2, phases C and D) at about 5600 BCE, which predates the traditional 5500–5400 BCE arrival of the Danish Ertebølle (Vang Petersen 1999, 10). In fact, the Ertebølle peak is short-lived. The upper part of figure 13.8 shows that when the combined Danish and Swedish data are taken into account, the population crashes at 5500–5400 BCE, when the radiocarbon curve dips very sharply.

It appears, then, that while there is no obvious relationship between change in point shape

and changing diet breadth or prey capture strategy between Kongemose and the Early Ertebølle period in Sweden, there is a connection between changing point shape and population decrease, a link that might result from the population-dependent processes suggested here.

The question remains as to the precise mechanisms affecting the case study populations. Do they crash due to climatic degradation? Greenland ice core oxygen isotope data is plotted and compared with the radiometric data in figure 13.8 to infer periods of climatic deterioration and amelioration (Weninger et al. 2005). If a climatic process detrimentally affected geographically circumscribed prehistoric groups at a time when ecological niches were at carrying capacity in Mesolithic southern Scandinavian, it is reasonable to assume sustainable off-take/environmental carrying capacity would be reduced, and consequent resource

stress could trigger a population crash. A fluctuating demographic pattern would be the long-term result. However, the well-known 8.2 kya cooling event does not appear to adversely affect the population proxy data in figure 13.8, so climatic degradation does not seem to be the direct explanation for the population drop at the end of the Kongemose, unless its effect was significantly lagged. Admittedly, relative population levels at the start (and end) of the Kongemose may be greater than the current archaeological record suggests due to the large number of currently submerged coastal sites, and it is feasible that the transition between Early, Middle, and Final Mesolithic may (perhaps) be smoother than the upper plot in figure 13.8 suggests. However, there is no *a priori* reason to believe that this is the case, as there is a significantly large sample size of occupation phases ($n = 89$) already, and dramatic population fluctuations can arise from entirely endogenous processes. In this context, it may be that key technological developments such as the bow–arrow and associated prey–capture strategies (Edinborough 2004) increased prehistoric environmental carrying capacity resulting in exaggerated “boom and bust” demographic patterns (cf. Read and Leblanc 2003).

CONCLUSION

This chapter has applied recent developments in evolutionary theory to an unusually extensive fine-grained archaeological data set. The data have been constrained by advanced chronological models at both the local and regional scales of analysis. Two key lithic point dimensions clearly characterized variation between projectile points found in the nine case study archaeological phases, and this is shown by confidence ellipsoids in figure 13.6. A long period of stability in the use of an indirect percussion technology and obliquely hafted points was succeeded in a short space of time by a change to transverse arrowheads produced by direct percussion.

Two hypotheses were considered as possible explanations of the observed patterns in the lithic data. The first of these, the possibility that the technological changes could be accounted for as a result of changing prey priorities, was falsified by carrying out a correspondence analysis (CA) of osteological count data from four archaeological phases spanning the entire duration of the case study (figure 13.7). This analysis suggested prey types remained constant while arrowheads varied in shape and complexity, so in evolutionary terms a simple functional-adaptation explanation is unlikely.

An alternative hypothesis was presented, one where complexity in lithic arrowhead technology directly relates to the size of the local population. A regional level model of relative population levels was constructed, using summed probability distributions of radiometric data as a proxy. As lithic arrowhead complexity was lost and point shape changed at a time when the population level was seen to drop dramatically, the results support a population-related mechanism as an explanation for the changes in the case study data, whether simple drift or a population-based learning-dependent process of the type modeled by Henrich (2004).

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FOURTEEN

Experimentation and Innovation in the Archaeological Record

A CASE STUDY IN TECHNOLOGICAL EVOLUTION FROM KODIAK, ALASKA

Ben Fitzhugh and A. Kate Trusler

THIS CHAPTER explores a dimension of technological change at the heart of archaeological inquiry. We ask the question “How did changes arise in the archaeological past?” and focus our efforts on an attempt to develop test implications for the risk-innovation model of technological evolution proposed by Fitzhugh (2001). Then we explore this model in the context of a case study from Kodiak, Alaska, in which small-scale hunter-gatherers shifted their flint-knapping repertoire from blade based to biface-based tool production. In this context, we ask whether this change was driven by a process of risk-driven innovativeness or whether people simply shifted from one to another familiar tool-making strategy as conditionally appropriate.

The archaeological record encodes a history of material continuities punctuated by changes. For more than a century, archaeologists have honed their skills in the description and interpretation of changing material patterns, yet we remain poorly equipped to explain the emergence of novelty—innovations of the past. Certainly, archaeologists have a long history of *interpreting* changes in material culture (often in

post hoc functional and/or social terms) and tend to be reasonably good at accounting for *lack of change*—in functional and/or cultural terms by means of the logic that persistence implies effectiveness. And without question archaeologists have convincingly characterized social organization and change in the past, if not necessarily explaining them. Yet, we still suffer from a lack of theory, method, or case study that satisfactorily accounts for *why* and *how* technological innovations occurred in the archaeological past when and where they did, and why they did not when and where they did not.

Past paradigms help illustrate the problem. Culture historians of the early twentieth century attempted to defer explanation of local changes with reference to diffusion from afar. Independent invention was recognized as an alternative to diffusion, but little effort was made to theorize innovation (or to understand the process of adoption as a component of diffusion). By contrast, processual archaeologists typically *assumed* that all novelties arose through processes of welfare-enhancing cultural adaptation to changes in physical and social conditions. While the

processualists at least took an explanatory perspective that accounted for innovation (while ignoring diffusion), neither processualists nor their predecessors actually sought to expose the *mechanisms* through which beneficial cultural novelties might have been generated. If adaptive novelties were sometimes introduced into a population through processes of innovation, how did past societies develop them? What prevented innovations from failing (or what happened when they did)? While processualist interpretations often generated compelling models of change, scholars in the tradition rarely sought to test the adaptationist assumptions on which they were built. Doing so would have required a methodology capable of measuring the adaptiveness of the given innovation. It was far easier to assume it.

We now understand that cultural transmission is theoretically capable of generating and maintaining considerable cultural variability that is not strongly (or even in some cases positively) correlated with any measure of adaptive success (e.g., Boyd and Richerson 1985; Dunnell 1978; Henrich 2004). We might take this revelation as just cause for abandoning all manner of adaptive frameworks. Alternatively, we could seek to improve our explanatory models and methods, both to predict when adaptive changes would be expected (and in which dimensions of behavior and material culture), but also to better understand how adaptive changes might have been generated. To do this, we need to better understand processes of innovation from the perspective of individual behavior as it relates to society and environment. Specifically, we need to model the motivating conditions that spur innovative behavior, the role of choice and change in material production, and the ways innovations spread through and between populations. We need to understand the costs, benefits, and risks associated with attempts to innovate, as well as the purely statistical factors that condition the relative “success” of particular innovations (Bentley and Shennan 2005; Brantingham 2003).

Some of these research themes have seen attention in recent decades, while others have not.

For example, technological studies have focused considerable attention on the processes and social contexts of innovation (e.g., contributions in Van der Leuw and Torrence 1989; Schiffer 2001). One trend has been to focus more keenly on the role of the individual and agency in the production of cultural change. Within this trend has been a focus on the processes through which individuals experience and participate in the production of innovations. From these and related studies, we now have a richer picture of innovation as a process. We have also learned that innovations often result from the combination of previously separate techniques, mediums, and applications (de Beaune 2004). For example, transfers of technique from one medium to another sometimes result in unanticipated technological potential, just as the personal computer and later the Internet made possible a flood of new derivative technologies and applications. Effectively these kind of developments result in a kind of “lateral move” from one peak to another in an “adaptive landscape” (*sensu* Wright 1932; cf. Brantingham, Kuhn, and Kerry 2004). The likelihood that technological evolution in this sense owes much to unintended consequences and historical contingencies throws cold water on attempts to explain technological evolution in purely functional or adaptive terms.

We now understand also that the adaptive functions to which many material objects become associated are often discovered after the development and initial spread of the innovations (see Gamble 1993). Archaeologists have speculated that several major technologies may have started as elite status goods, only later converting to more utilitarian technologies with broader application. This “prestige-first” process has been suggested for the development of pottery, agricultural intensification, and metallurgy, among others (Hayden 1998; Rice 1999; Vitelli 1989, 1998). These newer conceptions expand and enrich our appreciation of the possible contexts of technological change, but they remain largely speculative.

Even farther from adaptationist approaches, in some ways, are those of some evolutionary

archaeologists (EAs) who assume that the generation of novelty is undirected or effectively random—like genetic mutation (contributions in O'Brien 1996). Accordingly, change is understood to result from a sorting process, by which variants are selected from a field of variation and “reproduced” according to their functional utility (or, minimally, their lack of negative functionality). Like card players, people are seen as playing with a given deck of cards, actively shaping the course of the game only through the selective retention of those cards with the greatest value in the given contest. New card variants appear in the deck from time to time, but how or why is treated as an uninteresting or even irrelevant question—only the contribution of such novelties to overall variability is considered important. Once again, the process of innovation is left outside the explanatory frame of reference.

While most human behavioral ecologists (HBEs) continue to focus on strategic and behavioral dimensions of adaptation, some have also recently begun to explore technology and to contribute a fresh set of ideas, models, and assumptions to the field of material culture studies. Ugan, Bright, and Rogers (2003), for example, seek to explain why people sometimes choose to invest little in technology, even when more effective technologies are known and accessible. Consistent with the economic logic of HBE, these authors suggest that the marginal value of technological investment makes simpler technologies more efficient for many tasks. Bettinger, Winterhalder, and McElreath (2006) have revised and advanced this model, potentially rendering it more applicable to empirical testing. These and similar approaches open up opportunities for exploration, but even in these cases, technological innovation, the creation of unprecedented techniques and tools, remains unexplored.

This tendency of behavioral ecologists to focus on behavioral plasticity/flexibility within an existing repertoire, rather than the evolution of the repertoire itself, has led to acrimonious debate between supporters of HBE and those of EA (Boone and Smith 1998, with comments).

This debate exposes the weaknesses of both paradigms on the topic of cultural evolution. In HBE's case, it is the firm reliance on the phenotypic gambit (the otherwise useful assumption that adaptive solutions are already accessible within the extended phenotype of individuals) that neglects the processes by which people may sometimes try to extend their capabilities through exploration of untested—and potentially maladaptive—ideas and techniques. Creativity plays a passive role in most HBE models, limiting their potential to address macroevolutionary change. In the case of EA, as already noted, the problem is lack of attention to the process of innovation relative to selection. We must find better ways to address these and similar questions, if we want to explain the evolution of material culture in the past.

An additional approach, that of cultural transmission theory (CT), is gaining currency in archaeological discussions of the processes of material culture evolution. CT explores the processes by which cultural learning influences the transmission of cultural information, including the adaptive, maladaptive, and adaptively neutral information (see Boyd and Richerson 1985). Initially focused on the application of genetic models to hypothetical scenarios of cultural evolution, recent research has produced interesting applications to the archaeological record. For example, Bettinger and Eerkens (1999) present an analysis of the transmission of novel stone arrow technology across the Great Basin in which differences in early point craftsmanship are interpreted as evidence of differences in the degree of access to skillful production stages. In one case, the new tool users appear to have been taught the process; in the other, they sought to reverse engineer the tools after exposure to the end product.

From our perspective, CT provides an insightful framework for understanding how innovations can be transmitted through and between populations (or not). Invention itself is not far removed from transmission, and transmission is critical to any invention that has any significance

in the archaeological record. More to the point, how material traits are adopted, replicated, and modified is critical to the shape of evolution of material culture. Innovation (the broader term referring to processes of testing through using) is inherently embedded in processes of transmission. Cultural transmission events introduce the potential for innovation when transmission fidelity is of low quality and/or adopters make experimental modifications to some culturally transmitted characteristic based on insight or whim. And CT theory provides an excellent framework for exploring the statistical structuring of cultural transmission as well as a context for developing so-called neutral models of cultural change. So far, in our view, CT models have not provided satisfactory accounts for *why* people in the past or present actively invent when they do and not when they don't.

Importantly, we see HBE and CT as complementary, with CT predicting how cultural information can spread and change in a population context. CT research often assumes that individual actors base their decisions on conditional rationality (seeking to make the best decision with available information) and in this sense is consistent with HBE's assumption that humans *attempt* to engage in selectively optimal behavior.

Our approach in this chapter, building on earlier writings (Fitzhugh 2001, 2003), is to explore the potential role of innovative behavior in the context of phenotypic adaptation from a behavioral ecology perspective. We wish to examine the proposition that sensitivity to environmental (including cultural) conditions leads people to adjust their behavior according to known or available technological strategies and models, and that when these strategies and models are perceived to be insufficient, experimentation and innovation become increasingly attractive. While low-level innovation is likely a constant in human cultural evolution, perhaps occasionally resulting in significant technological changes through accumulation and chance, we assume that more often, attempts to make significant innovations will be favored only when available

alternatives ("adaptations") come to be seen as insufficient.² Following HBE, we assume here that decision rules are conditioned by evolved propensities to maximize survival and reproduction within social and ecological contexts.

THE RISK-INNOVATION MODEL

Fitzhugh (2001) proposes a model for technological innovation that predicts innovativeness will be stimulated when conditions favor risk-prone decision making. The punctuated record of stasis and change characterizing the archaeological record suggests that innovation is not a constantly occurring phenomenon. Instead of assuming that people produce novelties in more or less continuous and selectively random ways (necessary if we are to assume that variation is always available from which to select) or that people are inherently capable of inventing their way out of problems as needed (as commonly held in functionalist-adaptationist models), the risk-innovation model suggests that people become more innovation-prone (inventive, experimental, receptive of untested technologies from outside) when existing methods are perceived as insufficient to achieve some desired goal and when the uncertainty of trying something new is discounted against the enhanced certainty of failure using known techniques. Accordingly, the costs and risks of sinking time and resources in experimental technologies would tend to discourage innovation except in times where the costs and potential hazards of experimentation would be diminished relative to the perceived benefits of outperforming available methods. In egalitarian and organizationally simple societies, the main catalysts for innovative behavior, at least as far as technology is concerned, would be crises of one kind or another, in which the status quo would be seen as more hazardous than taking a chance with something new and untested, and where social responses would be ineffective (e.g., when everyone experiences the same hazard synchronously such that exchange will not resolve the problem).

Unlike many previous models, the risk-innovation model situates the motivation for technological change squarely with the individual actor—not the group as a whole. The individual orientation allows us to assume that some people may be more prone to invent and more receptive to innovations than others in their region or group. The possibility of interpersonal asymmetry in risk sensitivity becomes especially relevant in nonegalitarian contexts in which some individuals benefit differentially from technological innovations. Where elites control the products of subordinate labor, and especially the products of craft specialists, it becomes possible for innovation costs to be transferred to subordinates, insulating elites from the more immediate consequences of false starts and failed experiments. Put another way, where differentially available to a subset of the population, surplus capital (in physical or social resources) can be used to sustain higher levels of innovation by insulating investors from the consequences of short-term failure. This situation is only expected when social competition puts pressure on producers to maintain high levels of production (food for feasts, exquisite prestige goods for trade, military products for defense and offense, etc.). Because social competition between elites and would-be elites is often present in hierarchical societies, all else being equal, we might expect innovation rates to be generally higher in those contexts compared with egalitarian ones, controlling for the typically greater number of possible innovators in larger societies. However, in the most despotic of polities, innovation by nonelites might be discouraged by leaders who view innovation as a threat to political or economic monopolies. In this case, competition itself is suppressed.

Thus, we make the general prediction that contexts of increased interpersonal competition in technological productivity should elevate innovativeness irrespective of degree of social complexity. Conversely, circumstances that stifle competition should discourage technological innovation.

The advantage of the risk-innovation model is that it situates technological change in an ecological and sociopolitical framework that predicts when innovative behavior is most likely and thus when we might expect a greater probability of archaeologically identifiable innovations. It provides an explanatory mechanism for technological change (the creation of novelty) from which adaptive (or maladaptive) technologies could be generated—whether the eventual applications of the novelties are intended by their developers or not. A further advantage of the model is its testability—at least in principle. Indeed, two very basic predictions follow from the model:

1. Technological experimentation should increase in times of sustained economic and sociopolitical competition.
2. Rates of innovative successes and failures should increase during such times.

At archaeological time scales, we can expect that, compared with failed innovations, successes will dominate the archaeological record, represented as new technological classes or types in the archaeological record, while failures will have short life spans and should be underrepresented, but perhaps not invisible, in the archaeological record. Because there is no guarantee of success in innovation, enhanced innovativeness might be best explored through the concept of experimentation.

A major drawback of the model, like so many others, is the methodological difficulty inherent in its testing. Using the model to interpret archaeological changes in a post hoc fashion (e.g., Fitzhugh 2001) leaves the model's explanatory power unresolved. The distance between the clear predictions of the risk-innovation model and its empirical evaluation lies in the paucity of available methods and bridging arguments (middle-range theory) to align the predictions with archaeological evidence.

Over the past several years, we have experimented with a variety of methods suitable to applying and testing the risk-innovation model

in empirical cases. In the remainder of this chapter, we explore the potential of a method for looking at experimentation as a proxy for innovation in the archaeological record.

CHANGE IN STONE TOOL TECHNOLOGY IN COASTAL ALASKA

In this study, we seek to explore the possibility of invention and innovation in the archaeological record. We reason that inventive behavior is built on experimentation, probably with high frequencies of failure and—if ultimately successful—signs of technological improvement over time. Identifying invention leading to innovation should then be possible if we can locate evidence of experimentation and design improvements in the archaeological record. Failure to identify evidence of experimentation archaeologically could imply that processes of innovation were too rapid to be observed at the chronological resolution available in archaeological cases under examination, or that knowledge about the newly practiced technology was in fact already embedded in the cultural system of the group despite its lack of prior representation in the known archaeological record.

The context for this study is a hunter-gatherer archaeological site from southern Alaska dating to the earliest phase of known occupation of the Kodiak Archipelago. The technologies under examination are core and blade and biface reduction technologies. Following Fitzhugh (2001, 2003, 2004), we expect innovation to be reflected in this case as a result of the occupants' presumed status as early colonists with low but growing familiarity with local resources and raw materials. This status is argued on the basis of a pattern of declining exotic raw material use and rapid change in tools away from large blades best made on locally unavailable, large-nodule cores (Fitzhugh 2001, 2004). From the risk-innovation model, we hypothesize that flint-knapping colonists to this archipelago would experience a crisis-driven risk innovativeness, as they sought to produce tools more suitable to locally available raw materials and their relatively small nodule

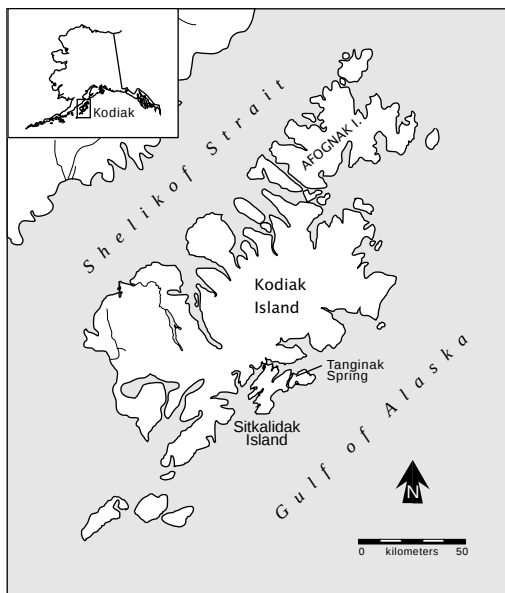


FIGURE 14.1 Map of the Kodiak Archipelago, showing the location of the Tanginak Spring site.

sizes. Support for this hypothesis could be found in evidence of new technological traditions taking over from older ones, along with experimentation with and gradual improvement in new flint-knapping strategies. Alternative hypotheses will be presented after introducing the case in question.

THE TANGINAK SPRING SITE

The Tanginak Spring site is a stratified, mid-Holocene campsite on the Kodiak Archipelago in the Gulf of Alaska (figure 14.1), occupied consistently if not continuously from 7,500 to 6,000 BP (Fitzhugh 2004). The site is situated on a knoll eight meters above sea level, overlooking a large salt marsh on the northeast end of Sitkalidak Island. At the time of occupation, a bay or lagoon filled the salt marsh (Mahrt 2006). A small freshwater spring seeps from the side of the knoll.

Tanginak Spring was found in 1993 during a systematic survey of the Sitkalidak Island area (Fitzhugh 2003). In 1994, Fitzhugh's survey crew excavated a 1 × 6-meter trench at the site, revealing the presence of a stratified sequence of occupation layers and fill going down almost 2 meters to a glacial till substrate. Subsequently,

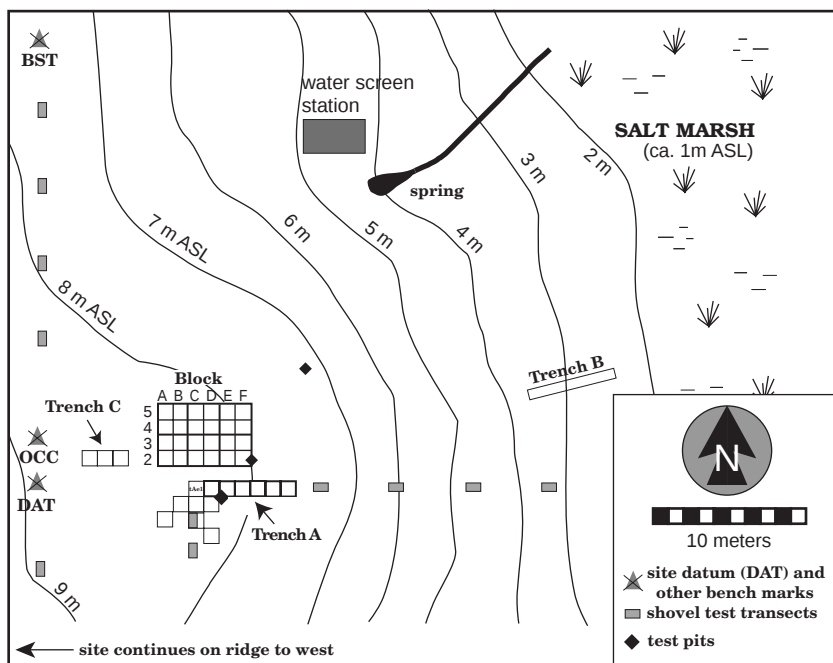


FIGURE 14.2 Topographic map of the Tanginak Spring site, showing the location of the Block excavation area and additional testing.

in 1998, 1999, 2001, and 2003, excavations were made at this site with crews of approximately twenty students. The portion of the excavation used in this analysis is the “Block Excavation” area (figure 14.2). This area has a systematic record of cultural material from the bottom to the top of the archaeological deposit. This area was excavated in arbitrary ten-centimeter vertical increments subdivided when appropriate at natural stratigraphic boundaries. The stratigraphy of the site is complex owing to the thin nature of occupation lenses, and the analysis presented here uses the arbitrary ten-centimeter levels. The tendency of occupants to resurface the site with several centimeters of fill provides reasonable stratigraphic separation of occupation layers, but it also means that some older materials were redeposited above younger surfaces. Radiocarbon dating of the sequence suggests that, for the most part, these reversals occur between adjacent stratigraphic layers and do not prevent the analysis of technological change at larger intervals. Post holes and other small pits cut into underlying strata provide a mechanism for some

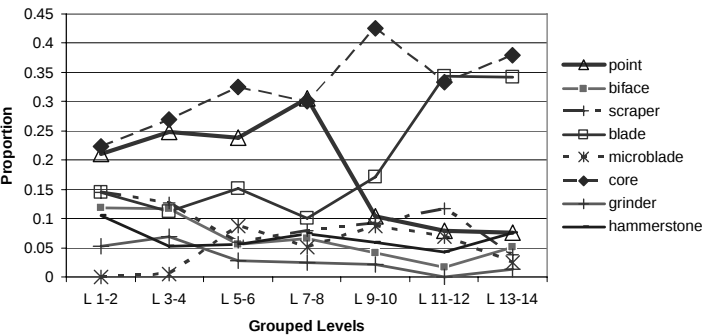
mixing. In terms of the analysis presented here, such disturbance will reduce the apparent differences between adjacent levels—somewhat smoothing the level-by-level distributions.

THE LITHIC ASSEMBLAGE

The artifact assemblage at the Tanginak Spring site is dominated by chipped stone tools. Very little organic material is preserved. Stone tools include macroblades (but no macrocores), microblades, and microcores, flake cores, bifacial “points” (leaf-shaped/bipoints; stemmed points), bifacial knives and scrapers, pecked stone lamps, hammerstones, and ochre grinding stones (hand stones and pestles).

The more carefully manufactured microcores are of the wedge shape denoted as Denali cores and common in the Alaskan interior from 10,500 to at least 7,000 BP (Dumond 1988). But there is a greater range of variation in these cores than is typical of the Denali cores from the interior, with some Tanginak cores being more conical and others more blocky. This greater variation, with continued manufacture of wedge-shaped cores, is a common feature of early to

FIGURE 14.3 Trends in the proportions of tool classes by paired levels in the Tanginak Spring site Block excavation. Here we see a dramatic decline in blades from levels 11–12 to levels 9–10, with a simultaneous increase in bifacial points and more gradual increase in other bifaces. Microblades continue to be used through the occupation, declining significantly in levels 1–4.



mid-Holocene microcores from the coastal regions of southern Alaska (see Ackerman 1992; Dumond and Knecht 2001; Steffian, Eufemio, and Saltonstall 2002). Cores used to produce flakes and bladelike flakes have much greater variation, most being opportunistically worked from shattered pebbles and cobbles. Many of these cores appear to have been formed into crude wedges.

A single burin tool was recovered from the excavation. It was made by striking burin spalls longitudinally down two edges of a medial macroblade segment from opposing corners. Burins are common in interior Denali assemblages and in Anangula tradition sites of the eastern Aleutians. Because many other characteristics of the Tanginak Spring site are similar to the earlier Early Anangula Tradition, there is reason to believe that Kodiak was colonized by a related group (Fitzhugh 2003, 2004). The near absence of burins (especially transverse burins) is therefore surprising. Because burins are interpreted as bone-carving tools, necessary especially for

creating microblade insert slots in bone points and knives, the large number of microblades in the absence of burins is also notable.

AN INTRIGUING TECHNOLOGICAL SHIFT

Stratigraphic analysis of tool classes reveals a striking change from the base of the site to its top, with a dramatic decline in large blades relative to bifaces (especially “points” and unspecified “bifaces”) (table 14.1 and figure 14.3). Cores also decline in relative importance through the occupation, but less dramatically, probably because “cores” were not easily divided into blade and flake cores (with the exception of a small sample of microcores). This pattern suggests a major change in technological organization, with a decline in blade-based tools with a concurrent increase in bifacial tools, especially points. It is notable that the Early Anangula Tradition from Umnak and Unalaska Islands in the Aleutians is dominated by core and blade technology, with the only recorded edge modification being unifacial flaking on macroblades. Stone points and

TABLE 14.1. Major Tool Classes from the Tanginak Spring Site’s Block Excavation Area

LEVELS	POINT	BIFACE	SCRAPER	BLADE	MICROBLADE	CORE	GRINDER	HAMMERSTONE	TOTAL
1–2	16	9	11	11	0	17	4	8	76
3–4	47	22	24	21	1	51	13	10	189
5–6	52	12	13	33	19	71	6	12	218
7–8	113	24	29	37	19	111	9	27	369
9–10	25	10	22	41	21	102	5	14	240
11–12	15	3	22	65	13	63	0	8	189
13–14	6	4	3	27	2	30	1	6	79
Total	274	84	124	235	75	445	38	85	1,360

other bifacial tools are unknown until about 7,500 BP (Aigner 1978; Dumond and Knecht 2001; Knecht and Davis 2001). Macroblades at the Tanginak Spring site are occasionally retouched unifacially (but not bifacially), and the oldest projectile points in the site include two made from macroblades and shaped/sharpened primarily by unifacial retouch.

What does this pattern of declining blades and increasing bifaces indicate in terms of the evolution of technology in the North Pacific region? In keeping with the theme of this volume and the theoretical issues with which we introduced this essay, we choose here to explore two alternate questions: (1) Did the change follow from a shift between two previously known technological strategies or “adaptations”—defined here as preexisting alternatives available for use as conditionally appropriate? (2) Alternatively, was the change driven by experimentation and the development of new technical knowledge (“research and development” by chance leading to a successful innovation)? According to the risk-innovation model, this is expected when existing technologies become difficult to maintain, such as could occur following colonization of a region with significantly different raw materials from the ancestral location.

These alternatives can be explored more specifically by means of the following three hypotheses and archaeological predictions, which address potential issues in manufacture and performance of the tools in question:

1. The earliest occupants of Tanginak and their putative ancestors in the eastern Aleutians were familiar with bifacial stone shaping techniques but for some reason chose not to use them until after 7,500 BP. In this case, we expect the shift to occur in proportion to changes in the balance of factors favoring one or the other technology, and we explicitly do not expect to see evidence of experimentation or a temporal trajectory of improving technique.
2. The knappers at Tanginak and their cultural relations across the region rediscovered

(reinvented) a tradition of bifacial production lost by their ancestors for at least a thousand years. In this case, we expect to see evidence of experimentation and improvement during the transitional period as bifaces increase in frequency relative to blades. Innovation of bifacial techniques could have occurred either through independent invention or through contact with biface-using cultures elsewhere. While few archaeological examples are known, we must assume that the occupants of the Tanginak Spring camp were embedded in a larger network of technological and social communication. The blade-to-biface pattern seems to be emerging as a fairly general one for the North Pacific Rim.

Archaeologists working in the eastern Aleutians are now beginning to recognize a broad regional trend away from unifacial core and blade technologies and increase in bifacial technology (e.g., Hatfield 2006). And the same pattern is reported for the coasts of mainland northeastern Asia at the about same time (Anatoly Kuznetsov, personal communication, 2006). This leads to the possibility that the Tanginak pattern is a local manifestation of a large-scale diffusion of bifacial production styles. But diffusion in the absence of wholesale cultural replacement would still require the introduction of a novel idea or technological repertoire and the receptivity of a receiver. Technological diffusion is itself risky for acceptors, as the introduced technique still needs to be learned.

Whether due to diffusion or independent invention, at the local level we expect innovation to require a process of experimentation and gradual improvement (declining “failure” rates as time passes). The time scale for this kind of reinvention would vary depending on a number of factors, such as the degree of novelty represented by the change (potentially measured in the number of unfamiliar actions in a production sequence) and, in the case of diffusion, the nature of contact between the donor and recipient population (e.g., Bettinger and Eerkens 1999). Given

these variables, the process of innovation development could range from days to generations. This creates a potential problem of equifinality as the technological change for both a shift between known technologies and an innovation *could* occur at too short an interval to be distinguished archaeologically. The gradual increase in bifacial points from levels 14 to 9 (a span of two hundred to five hundred years) suggests a multigenerational process, encouraging us to believe that in the case under examination, change did in fact occur at an archaeologically visible time scale.³

3. The new environmental context presented technological challenges in application—as opposed to tool production—that forced innovations in bifacial form (e.g., hafting, strength, sharpness, weight, penetration, aerodynamics, etc.), as expected when a technology is applied in an unfamiliar context. Challenges in the application of bifacial technology could have delayed the large-scale abandonment of blade technology (even if difficult to maintain) until improvements in bifacial tools could be perfected. In this case, we expect to see changes in tool forms and a reduction through time in tool variation without evidence of experimentation in manufacturing technique.

We explore these questions, first by looking for evidence of changes in the efficiency and effectiveness of lithic tool *manufacture* to explore the question of whether bifacial techniques were previously unknown *and* slow to be mastered. This is accomplished by looking at changes in frequencies of debitage as a measure of raw material waste and changes in breakage rates of bifacial tools (primarily projectile points). We then consider the possibility that bifacial tools themselves (“points,” in this case) saw refinement through time, as expected if innovations were made to improve the performance of bifacial tools. We do this by looking at standardization of projectile point form through the occupation levels at the site.

IDENTIFYING INNOVATIVENESS

Technological innovation and innovative technological applications require invention/adoption of novel strategies with initially uncertain outcomes. The development of a new reduction strategy and tool class should involve elevated levels of experimentation and a considerable rate of failure as artisans developed the requisite skill sets and finesse to select appropriate cores and base flakes and to shape, thin, and sharpen finished tools without breaking them during manufacture or rendering them unworkably thick and chunky (Callahan 1979). Application of the experimental tools would generate further information on performance that would feed back to changes in tool production, while also generating an archaeological record of relatively high failure rates.

From this, we expect innovation of a new bifacial point technology at the Tanginak Spring site to be indicated by an initially high rate of broken relative to complete projectile points and point preforms and a declining rate of fragmentation later, as knappers became more effective with this new technology. The change in dominance of blade to bifacial tools occurs between levels 13–14 and levels 9–10, and these technologies stabilize in relative frequency after levels 7–8. As a result, we expect the highest rates of production failure (broken bifaces) and production debris (waste products) to correspond to levels 13–14, with a trending decline in the proportion of such debris (debitage, shatter, and cores) relative to formal tools until levels 7–8.

The breakage data on points (figure 14.4) does not support the innovation hypothesis. If anything, there is an increase in broken points relative to whole ones later in the occupation (levels 1–6) compared with all older levels. This pattern parallels the increase in edge damage observed in the same later levels. We therefore conclude that breakage has more to do with operational damage than manufacture failure. The breakage data therefore are not relevant to the question of innovativeness. Incidentally, the breakage and edge damage data support the

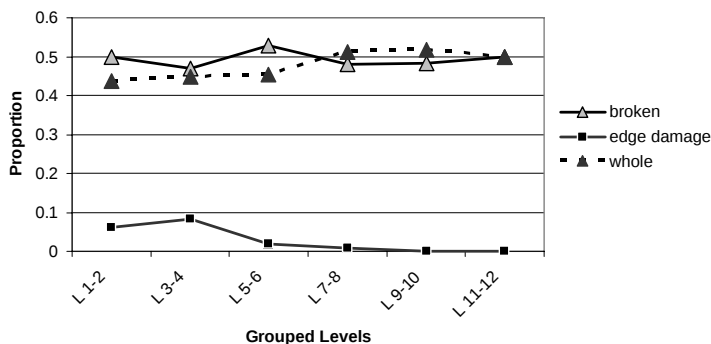


FIGURE 14.4 Proportional change in whole, broken, and edge-damaged (but whole) points from the Tanginak Spring site, Block excavation.

interpretation that bifaces are functional replacements for blades, where “bifacial points” were commonly used for cutting purposes, replacing large blades as knives.

Table 14.2 and figure 14.5 show trends in the ratios of flaked stone tools and chipped cores relative to flakes. Here, a larger ratio indicates fewer flakes per tool. These data again contradict the innovation hypothesis, suggesting that during the critical interval from levels 14 to 7, there was, if anything, a decrease in flint-knapping efficiency, rather than the reverse. While there might be several explanations for this, it appears that flint knappers were not getting better at their craft! More likely they were relaxing constraints on raw material conservation—a point we will return to later. These two analyses suggest that the increase in bifacial production (especially in what have conventionally been classified as “points” in this region) was a shift in known or

easily resurrected tool production methods, not a significant and risk-prone innovation.

Before rejecting the innovation hypothesis, we need to consider the possibility that the innovation we seek to document occurred away from the site, with the finished products (or preforms) arriving more or less fully formed. In that case, the breakage and debitage data for experimentation would not be represented in the Tanginak Spring assemblage. To evaluate that possibility, we turn to an analysis of flake type and examine ratios of different kinds of raw material used for tools relative to flakes. We assume that off-site production of part of the Tanginak Spring bifacial point assemblage would result in recovery of few thinning flakes and a disproportionate number of points compared with flakes made on nonlocal raw materials, with the mismatch increasing as stone points become more important in the assemblage.

TABLE 14.2. *Counts of Large FLakes (≥ 10 mm) and Flaked Tools Plus Cores, and the Ratio of Flaked Tools Plus Cores Over Flakes*

	FLAKES	FLAKED TOOLS + CORES	FLAKED TOOLS + CORES/FLAKES
Levels 1–2	1,894	64	0.03
Levels 3–4	2,469	166	0.07
Levels 5–6	4,672	200	0.04
Levels 7–8	17,341	333	0.02
Levels 9–10	5,340	221	0.04
Levels 11–12	3,325	181	0.05
Levels 13–14	1,233	72	0.06
Total	36,274	1,237	0.03

NOTE: Data are from the block excavation. Data here are plotted in figure 14.5.

FIGURE 14.5 Ratio of chipped stone tools plus cores to flakes larger than ten millimeters in the Tanginak Spring site, Block excavation.

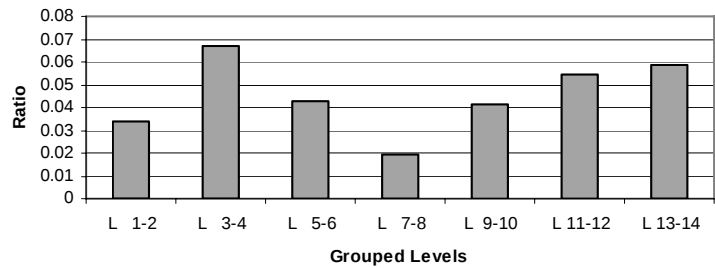


FIGURE 14.6 Trends in proportions of flake types from units C2 and D2, reflecting a relative decline in blade production and increase in bifacial thinning from levels 13–14 to levels 7–9.

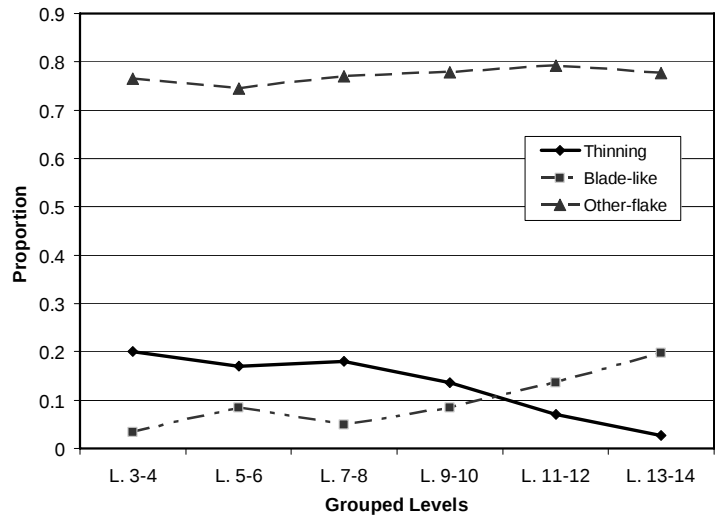


Figure 14.6 shows the proportional change in flake types (larger than ten millimeters) through the levels from the two excavation units (units C2 and D2 of the Block area) for which flake data have been carefully analyzed. We first note the lack of a dramatic change in the proportion of thinning flakes, bladelike flakes, or other flakes (assorted flakes with relatively obtuse platform angles, variable thickness, and/or irregular shapes). The assemblage is consistently dominated by “other flakes” that could have been produced by expedient or early-stage core reduction. Other evidence suggests that the bulk of flint knapping was for expedient core and flake tools, using locally available and relatively low-grade Tanginak chert. In figure 14.6, we see the shift from blades to bifaces reflected in the decline of bladelike flakes and the increase in thinning flakes exactly at the same levels that points increase relative to blades (figure 14.3). This

appears to support the idea that at least some of these bifaces were produced on site. This conclusion is strengthened by the observation that the most common raw material used to manufacture bifacial points, especially during the transition from levels 10–11 to 7–8 was Tanginak chert—the most local of raw materials, found on the beach in front of the site (figure 14.7). We conclude that the bifacial point assemblage is primarily of local manufacture. The lack of experimentation or trends in expected breakage rates are not due to importation of largely preshaped bifaces to the site.

Finally, we consider the possibility that innovation is represented in other aspects of bifacial form—namely, in the refinement of the bifacial tools themselves to improve performance. To examine this question, we classified the bifacial points into a formal typology based on attributes of the base and shoulder. We were reasonably comfortable breaking the available

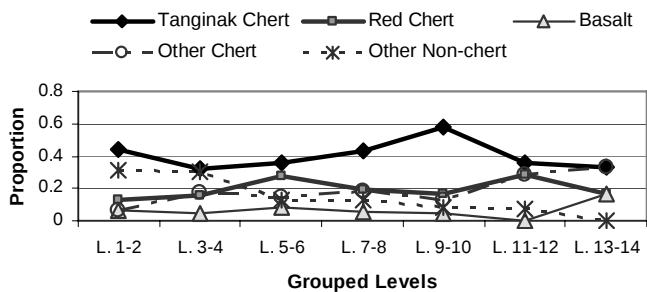


FIGURE 14.7 Proportional trends in raw material of bifacial points, showing the dominance of local Tanginak chert in the manufacture of these tools at Tanginak Spring site, Block excavation.

seventy-nine points into general categories of leaf shaped (“bipoint”), flat based, rounded based, and stemmed. An additional category was created for asymmetrical bifaces. Refinement in technique, as part of an innovative process to improve tool performance, was expected to result in a reduction in typological variance (fewer types) through the site occupation. In fact, we don’t see such a trend (table 14.3). Controlling for sample size, the richest (most typologically diverse) levels are 4, 5, 6, 7, 9, and 10 (i.e., these levels have more types than average given their sample size). Level 5 is particularly diverse/rich. Least rich levels are 3 and 8 followed by 1, 2, and 12. Since we expect richness to decrease with increased experience making the tools, we expect richness to be highest in earliest levels. It is not. Once again we are compelled to discount significant innovation occurring in this assemblage.

It is possible that each “type” we defined had a different application; for example, if one was a spear tip and another was a dart tip, then we might not expect a reduction in number of types through time, but instead a reduction in the variance of form through time within each class. This was harder to examine, but we chose to look at metric characteristics of the bifacial point assemblage to see if we could identify any systematic reduction in variance of attributes such as point length and width/thickness relative to length. There was no clear change in variance or trend in length observed for leaf-shaped or stemmed points (though each level shows some shift in mean and range). This suggests length was not an important characteristic for function, supporting the idea that length could vary through the use-life of each tool without reducing its utility. Variance in width/thickness measures showed no trends in most classes,

TABLE 14.3. *Number of Classes (Typological Richness) of Bifacial Projectile Point Types by Level*

LEVEL	TYPOTOLOGICAL RICHNESS	SAMPLE SIZE
1	1	1
2	1	2
3	2	11
4	2	4
5	3	6
6	3	9
7	4	15
8	3	17
9	3	9
10	2	4
11	0	0
12	1	1

NOTE: Maximum richness, in this case, is four types.

although stemmed points did become slightly thinner through time. There is also trend of declining frequency of leaf-shaped points relative to stemmed points from levels 9–10 to levels 3–4, which provides our only hint of a possible technical improvement through time at the site.

For the most part, these data seem to suggest a consistent production of point types through time. Points themselves are relatively stable in size and shape. There is scant evidence in these data to suggest technological innovation among bifacial projectile points any more than there was to support innovation in bifacial flaking techniques themselves.

DISCUSSION

Taken together, these analyses argue against the hypothesis that a lengthy process of experimentation led to the innovation of bifacial techniques in parallel with the decline of core and blade forms at Tanginak Spring. We feel that these data instead support the alternate hypothesis that the occupants of the site were familiar and competent bifacial flint knappers even early in the occupation. The fact that they did not seem to be much interested in bifacial techniques initially probably reflects other considerations that favored the use of a manufacturing technology more conservative of raw materials or better suited to the lifestyle of the time.

The hypothesis, now provisionally rejected, that bifacial technologies were reinvented by early occupants of the Tanginak Spring site was based on the assumption that ancestral peoples had lost bifacial techniques previously available to their ancestors. It is not unreasonable to expect that a cultural tradition could lose knowledge of production techniques if they remained unused for generations or centuries and if the population were isolated from other groups that retained the techniques. Such cultural loss has been reported famously from Tasmania (Bowdler 1982; Jones 1984), and Henrich (2004) has presented a compelling model to explain how this kind of loss could occur among small and isolated populations.⁴ In the case of the

Tanginak Spring assemblage, however, we see no evidence to suggest that bifacial techniques were unfamiliar when they started reentering the technological repertoire, suggesting either that they had long been familiar—if strategically underutilized—or that the innovation of bifacial techniques and tools was a much faster process than we envision.

On balance, we consider it most likely that flint knappers at Tanginak shifted to bifacial technologies with little effort because they already knew how to make them but did not previously, because blade technology was more useful. That is, we find support for the hypothesis that biface production was a preexisting “adaptation” strategy reactivated when useful, not something invented from scratch in a time of need.⁵ If so, why did early occupants of this site shift to bifacial technology during the first third of the occupation? Drawing on the concepts of maintainability, reliability, expediency, and technological risk (Bleed 1986; Nelson 1991; Torrence 1983, 1989), we suspect that the risks of technological failure in hunter-gatherer food-getting technology may help us explain the transition. Compared with most gathering activities, hunting tends to have higher spatial and temporal risk. Thus, we expect hunters to prefer tools that will minimize hunting failure, especially when lost opportunities are particularly costly.

Torrence (1989) suggests that when technologies can fail during critical moments with a significant negative impact on welfare, people should emphasize technologies with overworked or redundant components. In this case, failure of one component is balanced by another. Having extra arrows in one’s quiver or a safety on a gun are examples of security measures designed for reliability. Manufacturing reliable tools demands downtime for tool manufacture and repair and should be more common where schedules permit (or compel) periods of tool work that do not compete with activities such as traveling or foraging. Maintainable tools are those that are easily repaired in the field during critical activities. In this case, the attempt is made to avert failure by repairing tools on the

spot. Sharpening a knife during butchery or repairing a damaged boat skin would be appropriate examples. Finally, expedient technologies are those that require little formal preparation and investment and typically receive little curatorial care.

The Tanginak Spring assemblage may be understood using a combination of these elements. First, the shift from blades to biface production seems in part to reflect the replacement of blade-based knives in favor of bifacially flaked knives. This could reflect greater investment of time in reliability. Blades are easily replaced with a minimum of raw material once the core is prepared. Bifaces require more raw material and time to manufacture, but they are more likely to perform consistently and repetitively without need for repair or constant sharpening. We assume that larger blades were probably processing tools replaced by a combination of expedient flake tools and bifacial cutting tools (including the multipurpose “points”). This shift may have been encouraged around Kodiak by the general lack of raw material nodules big enough for macroblade production (Fitzhugh 2004) and by a shift in mobility strategies that led people to spend more time in camp accumulating and working raw materials from near and far.

Putting these ideas together, we suggest the following model for further examination and elaboration: Coastal peoples from Kodiak, the eastern Aleutians, and perhaps western Beringia abandoned bifacial technologies during the global warm period from about 9,000 to 7,000 BP as they moved out onto the coastal and island zones of the North Pacific. During these times, winters may have been warm enough to permit opportunistic residential mobility throughout the year. Relatively high mobility favored conservation of stone raw materials through core and blade technologies. Marine and bird bones were comparatively more ubiquitous than quality knapping stone and could be fashioned into piercing tools and armed with microblades or self-armed. Meanwhile, social and trade interactions with neighboring groups helped to maintain cultural knowledge of bifacial techniques,

even though they were rarely, if ever, used for coastal living at the time.

As climate cooled, sea levels stabilized, and populations grew on the increasingly stable coastal ecosystems (Yesner 1998), maritime hunter-gatherers spent more time in smaller territories, returning often to the same favorite campsites, such as the Tanginak Spring site. There they could accumulate raw materials and invest in the more reliable bifacial tools that were previously too costly to maintain. Reliability was important, because the cooling climate reduced the amount of time available for foraging, especially in the stormy months of winter. Cultural transmission coupled with pressure to take up more reliable techniques, then encouraged the parallel shift to bifacial techniques around the North Pacific rim. Evaluation of this model will require more detailed future analysis of the available archaeological information for this transition around the North Pacific.

CONCLUSION

The case study presented in this chapter serves to illustrate ways that archaeologists can attempt to identify periods of innovativeness in the archaeological record. This is critical if we are to better understand processes of technological change and the contexts that encourage and discourage it. While archaeologists have often invoked adaptive models to explain material patterns in the archaeological record, these accounts usually fail to consider the mechanisms by which innovations come about; instead, they seem to assume that innovations simply arise when needed, thus justifying the functionalist logic of adaptationist explanations.

We have argued here that technological changes could arise from one of two basic processes. The first is invention or its close parallel—adoption through diffusion. All successful novelties were invented somewhere and then spread through diffusion, but at every step, this process requires experimentation in design and implementation before people can rely on the new technology. An alternative is that

novelty in the archaeological record may often not represent innovation in the behavioral context. People know how to do many things that they do not do regularly. It is in this context that adaptive models are the most justifiable, because the only mechanism needed to explain the change is a change in the selective environment, triggering an adjustment in the deployment of known technologies. This is the true phenotypic plasticity—when a subset of available behaviors or technological products are employed according to individual understandings of the best action or tool for the job at hand. Invention and adoption require the additional consideration of the risk and uncertainty of experimentation—characteristics that should inhibit innovation when acceptable options remain available.

In this chapter, we have attempted to advance the risk-innovation model by exploring its testability in an archaeological case of technological change. This has been possible because of the sufficiently long time record and detailed archaeological data available. Even so, we were compelled by the results of our analysis to conclude that innovation was not directly involved in the technological changes we set out to understand. We believe this result illustrates the proper application of scientific methodology to archaeological problems. Our analysis also highlights the challenges of innovation studies in archaeology. Identifying examples of true innovation may be exceedingly difficult given the need of a high-resolution record with large samples. Lithics may not be the best material for such an analysis, given the rather limited set of skills required to make a wide range of products. On the other hand, technologies of greater complexity are often also necessarily harder to partition into appropriately robust analytical categories. More methodological work is desirable to further test the risk-innovation model.

This chapter seeks to take an incremental step in our understanding of technological change by focusing attention on the empirical problem of identifying experimentation and innovation in the archaeological record. It introduces the possibility that technological change

may not always, or even often, be “innovative” or “evolutionary.” Until we improve our ability to identify innovativeness in the archaeological record, we will remain poorly prepared to study evolutionary change in an archaeological context. We suggest that looking for experimentation in the archaeological record is one way forward.

Acknowledgments. We thank Stephen Shennan for his patience and persistent interest in this essay and two anonymous reviewers for very helpful advice. Joe Henrich and James Taylor also provided helpful comments on a later draft. Thanks go to the many students who worked in the field and lab on the Tanginak Spring study. The community of Old Harbor and the Alutiiq Museum in Kodiak provided unbelievable encouragement and support. The University of Washington Summer Quarter and the Program on Climate Change funded the fieldwork at the Tanginak Spring site.

NOTES

1. In this chapter, *invention* refers to the creation of novelty prior to substantial testing to determine its performance characteristics. *Innovation* refers to the broader process of assessing the performance utility of an invention or introduction prior to its broad adoption in the material repertoire of a cultural group. In practice, these two processes are often overlapping and iterative. Innovation also subsumes the process of diffusion, in which any implement of material culture not currently in circulation among a group, whether unique or just novel to the group concerned, must undergo evaluation—with possible alteration—before it is likely to gain currency in the group’s material repertoire.
2. *Adaptation* is a term with many definitions and uses both passive characteristics (e.g., “an adaptation for *x*”) and active (e.g., “an adaptation of the original form”). We use the term *adaptation* in this chapter in a more limited sense to refer to known strategies that could be used as needed to distinguish between *inventions*, for which the adaptive utility is unknown prior to experimentation. In the broader sense, inventions and innovations

- become adaptations if a function is found for them. The point here is not to quibble over semantics but to identify a difference in the processes by which people in the past confronted technological choices and challenges.
3. We are compelled to acknowledge that the modest degree of stratigraphic disturbance by means of excavated post holes and pits and the nature of an analysis by arbitrary levels already discussed could account for the gradual trend observed in the archaeological record where an abrupt shift may have actually characterized the behavioral pattern. Currently, we do not have a good way to estimate the importance of this possible effect.
 4. Henrich models technological loss as a statistical problem of cultural transmission in small populations. Why toolmakers might choose to focus on a subset of the available technological repertoire to the point that cultural transmission fails to reproduce useful alternatives deserves more attention. The answer may relate to a sustained period in which adaptive advantage was provided by expedient technologies (see Ugan et al. 2003). Then the question becomes, Why would people not have eventually reinvented some of the more ubiquitous technologies, like fishhooks and harpoons, given the availability of archaeological examples from earlier prehistory? Perhaps the retained technologies were never found lacking, and Tasmanians did not engage in risk-prone innovation. In general, the idea that small and isolated populations are less able to innovate over such long time spans seems inconsistent with the archaeological record of hunter-gatherers.
 5. Note this argument differs importantly from adaptationist models that invoke functional logic to explain the evolution of new designs.

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Social Evolution

FIFTEEN

Mind the Bonding Gap

CONSTRAINTS ON THE EVOLUTION OF HOMININ SOCIETIES

R. I. M. Dunbar

MODERN HUMANS live in large complex societies, and these must have evolved over time from more conventional primate-like social groups. This is not, however, a straightforward issue: rather, I shall argue here that the nature of bonding in primate societies is such that there are natural glass ceilings on the size and structure of primate social systems, and it was necessary, in the course of hominin evolution, to find ways of circumventing the limitations that these imposed.

There are two main aspects to this argument. One concerns the cognitive demands of sociality, the other the mechanisms of bonding needed to maintain social cohesion through time. Neither of these are trivial issues, and I shall argue that much of what we might see as defining human nature and the human condition arises directly out of attempts to solve these two problems. To set the scene, however, I need to begin by sketching in the essential details of how primate social systems function. This provides the ground plan from which our earliest ancestors branched out on the way to the modern human condition.

PRIMATE SOCIETIES

Primate societies are characterized by two key features—or, at least, I shall focus here on two. One is that they depend on an intense level of social bonding among the members. We do not really understand the nature of this bonding process, but it does seem to be qualitatively different from that seen in other nonprimate animal species, and it seems to be dependent on particularly sophisticated forms of social cognition that, again, appear to be unique to primates. This intense bonding, and the cognitive capacities that underpin it, is crucial for the long-lasting alliances or coalitions that primates form within their groups. Harcourt (1992) has pointed out that primate (or, at least, monkey and ape) alliances differ from those found in all other species of animals in that they are established long before they are needed: they have a time dimension that allows them to be called on, fully formed, when needed. In contrast, the alliances of other species seem to be much more “of the moment” and lack this long-term commitment.

The second feature is that primates bond their social groups by grooming each other. Social grooming occupies an extraordinary amount of time in the more social species—as much as 20 percent of the day. This is a remarkable amount of time for any species to devote to what must otherwise be considered so inconsequential an activity, given the importance of foraging and the business of reproduction. In addition, we don't really understand how social (as opposed to self-) grooming does this, although we know that frequent grooming is integral to the effectiveness with which alliances function (see, e.g., Dunbar 1984). We know that grooming is an effective trigger for the release of endorphins (Keverne, Martensz, and Tuite 1989) and that these have an important effect in relaxing an animal (they induce a mild opiate high and are a powerful psychological reward in their own right). I suspect that the endorphin high produced by grooming is instrumental in creating a sense of trust and commitment between the two animals concerned, thereby providing the psychological substrate for alliances. However, once again, we do not really know how this works.

The role of cognition in primate sociality has been explored in some considerable detail in relation to brain evolution. It has always been assumed that there is a general relationship between brain volume and cognitive capacity (“intelligence” in some general sense) (Jerison 1973). More recent analyses have demonstrated that primate brain evolution seems to have been driven specifically by the demands of sociality (the social brain hypothesis) (Sawaguchi and Kudo 1990; Dunbar 1992, 1998; Barton 1996; Barton and Dunbar 1997). These findings have now been extended to ungulates, carnivores, some insectivores (Dunbar and Bever 1998; Marino 2004; Pérez-Barbería and Gordon 2005; Shultz and Dunbar 2006) and even bats, suggesting that the social brain hypothesis may in fact apply more widely. Although the essential basis of this claim has focused on a relationship between social group size and brain (or, more specifically, neocortex) size, in fact the claim is really about the complexity of social

relationships, and a number of more recent studies have demonstrated that aspects of behavioral complexity do correlate with neocortex size in primates (number of grooming partners: Kudo and Dunbar 2001; male mating strategies: Pawłowski, Lowen, and Dunbar 1998; rates of deception: Byrne and Corp 2004; frequency of social play: Lewis 2001; coalition formation: Dunbar and Shultz 2007).

Nonetheless, the generic relationship between neocortex volume and social group size provides us with simple means of estimating natural group sizes in other species. Indeed, it seems to work quite well for nonhuman primates, even when we have to estimate neocortex ratios indirectly from cranial volumes (Dunbar 1995). As it happens, there is a relatively tight scaling relationship between overall brain size and the size of most brain components, so that estimating neocortex volumes from cranial volumes is not a difficult task (even though, inevitably, it comes with a modest degree of error variance) since cranial capacities are one of the first things that palaeoanthropologists describe for new fossils whenever even partial crania are available. For modern humans, however, we can at least rely on actual neocortex volumes, since these are given in the same database (Stephan, Frahm, and Baron 1981) as those used in the original analyses of nonhuman primates. For modern humans, the predicted group size of about 150 matches remarkably well a particular level of grouping that is characteristic of many human societies drawn from different ethnographic samples (Dunbar 1993, 1996; Zhou et al. 2005).

Aiello and Dunbar (1993) exploited these relationships to estimate social group size for hominin populations, with neocortex ratios estimated from cranial volumes. They showed that group size remains well within the living ape range among australopiths (50–60), begins to rise slowly with *Homo erectus* (ca. 60–80), and takes off exponentially with the appearance of archaic humans (*H. heidelbergensis* and allies) around 0.5 mya toward the 150 characteristic of modern humans.

The existence of these grouping levels is principally an issue in multilevel selection. They exist because their members need them to solve different kinds of ecological problem that bear on successful reproduction for the individual members. Primate social groups are implicit social contracts: individuals give up some of their immediate demands and expectations (i.e., they bear a cost) in the interest of greater gains in the long run. Thus, I forego some efficiency in foraging (I have to travel much farther if there are more people in the group, and my feeding bouts may be disrupted by others who occasionally steal my feeding site or food), but I expect these costs to be more than offset by gains in survival through, for example, reduced predation risk that derive from being in a large group (van Schaik 1982; Dunbar 1988).

The fact that primate social systems are multilevel in this sense means that they are especially susceptible to free riders (those who take the benefits of sociality but don't pay all the costs—i.e., accept the benefits of living in the group but aren't prepared to forego enough of their immediate personal demands). Such individuals trade on the generosity of other group members. But since this imposes additional costs on these individuals, they should become increasingly reluctant to bear these as their intensity mounts and more and more individuals are tempted to free ride. The inevitable outcome of such an arms' race is the collapse and dispersal of the group when its members are no longer prepared to bear the costs of free riding (Enquist and Leimar 1993; Nettle and Dunbar 1997).

THE PROBLEM OF SOCIAL COHESION

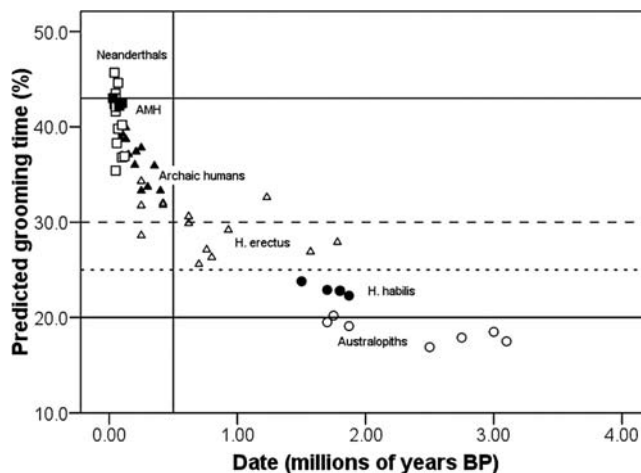
The substantive issue here is how these increasingly large groups are kept cohesive in the face of the centrifugal forces of free riding. For primates, this principally seems to involve social grooming and the way grooming serves to build alliances and friendships. Grooming time is positively correlated with social group size in Old World monkeys and Apes (Dunbar 1991),

though this does not necessarily mean that grooming is evenly distributed around all members of the group. In fact, what seems to happen as group size increases is that individuals invest more heavily in their core social partners, as though to strengthen those relationships that really matter to them (Dunbar 1984).

Irrespective of how this works, the substantive issue is that grooming time increases more or less linearly with group size. If hominins behaved as conventional primates and bonded their groups by grooming alone, then we can determine the demand for grooming time for different hominin populations by interpolating group sizes predicted from cranial volumes into the graph for required grooming time in monkeys and apes. This results in a slowly accelerating curve, which, of course, tracks the pattern of increase in brain size (see Aiello and Dunbar 1993). It reaches its maximum (more or less) with modern humans and an estimated grooming time requirement of around 45 percent—that is, almost half the day having to be spent engaged in grooming. Clearly, modern humans do not spend that amount of time engaged in social interaction; in fact, based on a sample of seven populations representative of a wide range of Old World cultures and economies, modern humans spend about 20 percent of their time in social interaction (Dunbar 1998b). This turns out to be virtually the same as the maximum time devoted to social grooming by nonhuman primates (Dunbar 1993). In effect, humans devote the maximum time that any primate does (or can afford to devote?) to social interaction, but somehow they use that time more efficiently in terms of its impact on social bonding.

I have argued elsewhere that what allows modern humans to bridge this gap is language (Dunbar 1993, 1996). Language allows us to cut through the time constraint because we can (1) walk and talk at the same time (whereas grooming is a dedicated one-on-one activity, even in modern humans), (2) use language to find out about what is happening elsewhere in the community (whereas primates can only

FIGURE 15.1 Predicted grooming time for individual hominid populations. Grooming time is predicted from group size (using the equation given by Lehmann et al. 2007), which in turn is predicted by neocortex ratio estimated from cranial volume (following Dunbar 2003a). Individual populations are based on average cranial volume for all crania found at the same site within a fifty thousand-year time span.



know about what they see for themselves), and (3) use language for both advertising and policing (neither of which nonhuman primates can do).

However, while language clearly allows us to overcome the constraints of time, it does so at a cost: by not engaging in the physical act of grooming, we inevitably lose what seems to be one of the core underpinning features of grooming—namely, its psychopharmacological properties. Since these seem to be the principal process whereby grooming creates its bonding effect, we have to ask whether something critical is lost with the acquisition of language. Of course, it is true that grooming has not entirely disappeared altogether—we still do a lot of grooming in the form of petting, cuddling, stroking, and sometimes even as real grooming in which bits are removed from hair or spots picked. However, it is evident that this form of activity is very restricted in its social distribution: we do not groom with everyone in our social circle. Grooming remains a very intimate activity to be engaged in only with our nearest and dearest. Attempts to stroke and cuddle less intimate members of our social circle tend to be viewed with alarm and anything but feelings of warmth and attraction, and sometimes with outright jealousy on the part of our nearest and dearest.

We can put this into its archaeological context by mapping grooming time requirements for individual hominin populations onto the time scale of hominin evolution, following Aiello and

Dunbar (1993). Figure 15.1 is a modified version of that given in Aiello and Dunbar (1993). Whereas the original plotted predicted grooming time for individual fossils (based on individual crania), figure 15.1 plots these values for population averages: a population is taken to be all the crania found at a specific site (or nearby cluster of sites) over a fifty thousand-year time span. In addition to this modification, I have used updated equations for calculating group size from neocortex ratio (in this case, the equation for hominoids given in Dunbar 1993) and a new equation for calculating grooming time from group size (based on new analyses using an updated database: Lehmann, Korstjens, and Dunbar 2007). The two horizontal lines on the graph identify the limiting amount of time devoted to social interaction by Old World monkeys and apes (about 20 percent) and the amount of grooming time that would be required by modern humans to bond social groups of about 150 individuals (about 45 percent). The difference between these two constitutes the “bonding gap” that needs to be filled.

BRIDGING THE BONDING GAP

Two features of human behavior seem to be ideal candidates as potential mechanisms for bonding. One is laughter; the other is music (and by music here, I mean both vocal music, or singing, and dance). Not only are these universal

features of modern human behavior, they are also peculiar to modern humans among the extant primates (though chimpanzees, at least, share with us a behavior that is homologous to laughter; Provine 2000; Waller and Dunbar 2005). It is important to appreciate that laughter in humans differs from that in chimpanzees in both the frequency and range of circumstances under which it occurs, as well as in some details of its production (see Provine 2000). Both laughter and music are, however, interesting because they seem to tap into neurological roots that are very different to those used for language: while language is mainly a left hemisphere phenomenon, both laughter and music are primarily right hemisphere phenomena (Bever and Chiarello 1974). These right hemisphere processes seem to tap into more directly emotional channels and may, perhaps, be more ancient than the left hemisphere language processes. More importantly in the present context, they also share with grooming the fact that they are both extremely good at triggering the release of endorphins. We have preliminary experimental evidence on this for both.

My proposal, then, is that laughter and music emerged relatively early—long before the evolution of language—as mechanisms for bonding social groups. Moreover, I would argue that they evolved in that order, with laughter providing a platform for the subsequent evolution of music. One reason for suggesting this is that social laughter seems to involve not only segmentation but entraining of vocal rhythms, both of which are crucial for music. Since laughter is shared (albeit in more primitive form) with chimpanzees, the most plausible sequence is that laughter appeared early during hominin evolutionary history and was later exploited in the evolution of music (at least in its vocal form). Some additional support for this proposal is offered by McDermott and Hauser's (2007) failure to find any evidence for musical understanding in New World tamarin monkeys; although this does not necessarily imply that such an ability is not present in Old World monkeys (or, more importantly perhaps, in apes),

this result does make the case for prioritizing a musical ability in nonhuman primates rather less strong.

Quite how early laughter might have been exploited for bonding is not clear. It is unlikely that it was present among the australopiths (other than in its basal chimpanzee-like form) since predicted australopithecine (including *H. habilis*) group sizes are well within the range of those observed in chimpanzees, and the grooming time requirements thereby imposed on them are not significantly greater than the limiting value seen in nonhuman primates (i.e., 20 percent). Since some compression of time budgets is possible, it seems unlikely that there would be significant pressure to evolve additional mechanisms to supplement the conventional bonding processes (i.e., grooming) much before the demand for grooming time reached 25 percent. In any case, as we know from living primates, those with very large social groups (e.g., gelada) already use vocal exchanges (in the form of chorusing) to supplement grooming while they are feeding as a form of "grooming at a distance."

Since the minimum grooming requirement for *erectus* populations is 25 percent (figure 15.1), one plausible hypothesis would be that laughter (if that is what came first) evolved into a recognizably modern form with the earliest *erectus* populations, some time around 2 mya. What we cannot at present say is by how much laughter would have allowed early hominins to increase group size beyond the limit set by conventional grooming (approximately 50–60 individuals). There is perhaps a hint in the *erectus* data to suggest that later populations had larger group sizes than the earlier ones (mean sizes of 81.3 vs. before 93.3 and after 0.7 mya, respectively), but the difference is only significant if we remove the early-phase outlier (Olduvai at 1.23 mya) (ANOVA: $F_{1,11} = 4.15$, $p = 0.045$). However, if this difference is real, it might represent another point at which a step-change occurs. This would correspond to a grooming time equivalent of about 30 percent of available time. A critical date of around 0.7 mya is perhaps close enough

to the climatic event of 0.9 mya (deMonocal and Bloemendal 1995; Vrba 1995; deMenocal 2004) to be interesting: the cooling and drying that occurred at this point may have been enough to force occupation of more open habitats and/or wider ranging, thus requiring a further increase in group size.

It is possible that this represents the point at which music came onstream. There is, however, a further marked disjuncture in brain size, group size, and/or grooming time corresponding to the appearance of archaic humans at about 0.5 mya, with a step-change in group size to about 100 individuals and a grooming time requirement of about 33 percent. This also corresponds to the point at which we find the appearance of anatomical markers for voice control (enlarged hypoglossal canal¹ and thoracic vertebral column: Kay, Cartmill, and Balow 1998; MacLarnon and Hewitt 1999). Since these anatomical markers almost certainly signal the appearance of either speech or singing (a phenomenon that is even more dependent on voice control than speech), we can probably define fairly clear limits around the time at which this next phase took off at some time between 0.7 and 0.5 mya.

An alternative hypothesis would be that music (or chorusing exchanges) evolved first and allowed group size to increase beyond the limits set by grooming. This would have some merit in that it would allow music to evolve out of the natural chorusing exchanges seen in species like the gelada who use (presumably amusical) vocal exchanges as a form of grooming at a distance. In this species, grooming partners engage in highly complex contact calling exchanges that often end up as a full chorus of the entire harem. Much of this goes on while the animals are feeding, so that chorusing acts as a form of grooming at a distance while the animals are feeding and unable to groom. It would not be difficult to convert this form of countercalling into synchronized (wordless) singing. Alternatively, with musical chorusing in place, laughter might then be seen as a late adjunct to language. However, the fact that

laughter has a homologue in nonhuman primates, whereas musical appreciation seems not to, makes this sequence less convincing than the alternative.

Both music and laughter continue to play an important role in modern human bonding, of course. The frequency with which laughter occurs in normal human conversation (Seepersand 1999) suggests that the behavior is not some trivial by-product of conversational activity but rather may itself be one of the goals of conversation. Indeed, it is not too implausible to suggest that language exists to tell jokes.

COGNITION AND CULTURE

It is evident, of course, that brain (and neocortex) size increases dramatically after the appearance of archaic humans (*H. heidelbergensis* and allies) at about 0.5 mya. Insofar as group size correlates with neocortex size, this therefore is also a period during which there is a correspondingly rapid increase in group size over a very short period of time (a 50 percent increase from about 100 to about 150 in no more than 300,000 years). Although we cannot say much about the limits that music and laughter as bonding mechanisms would impose on group size, it seems likely that so rapid an increase must have been associated with considerable social and demographic strain. Maintaining cohesion during such a period of rapid increase could not have been easy. My claim is, therefore, that the destructive effects of free riding would have been so intense as to necessitate additional more powerful mechanisms for enforcing group cohesion. I would suggest that that mechanism was religion.

Religion has some interesting properties in this context. Almost every religion is associated with rituals of one kind or another. Those rituals commonly involve the imposition (often self-imposition) of pain and/or stress on the musculature. These mechanisms include, among others, adopting awkward or uncomfortable postures (e.g., kneeling), singing, dancing (if only in the form of repetitive swaying), and

ritualized hand movements (e.g., counting beads), as well as the deliberate infliction of pain (flagellation, wearing uncomfortable clothes, stigmata, etc.). Pain and physical stress are particularly effective ways of triggering the release of endorphins, since the principal function of endorphins lies in their role as part of the body's pain control system. The intellectual component of religion plays a crucial role in this because it provides a means of ensuring that these activities are (1) done regularly and, perhaps more importantly, (2) done communally. Endorphins seem to work as a mechanism for bonding only when the activities that trigger endorphin release are done socially. It is easy to stimulate endorphin production, but doing so on one's own does not seem to create that sense of "belongingness" that is critical to social bonding.

The problem here is that using religion to create the circumstances in which to engage in these rituals is not that easy. Religion is actually cognitively very demanding, since it requires the individual to imagine that there is another (usually spirit) world quite distinct from, yet parallel to, the world in which we live. This requires minimally second-order intentionality, since second-order intentionality is a prerequisite for being able to imagine that the world could be other than as we immediately experience it. Second-order intentionality (or theory of mind, or mentalizing, as it is better known in the psychology literature) is equivalent to being able to say, "I believe that you think [that something is the case]." Only once children have acquired theory of mind (at about five years old) can they engage in fictive or imaginative play or recognize that two people can believe different things about the state of the world (Astington 1993; Mitchell 1997). There is no evidence to suggest that any nonhuman animal, other than perhaps great apes, can aspire to second-order intentionality (Tomasello and Call 1999; O'Connell and Dunbar 2003).

However, it is clear that normal adult humans can achieve considerably better than mere second-order intentionality (the state

characteristic of four- or five-year-old children). On the standard scale of intentionality, it seems that the natural limit for adult humans is at about fifth² order (Kinderman, Dunbar, and Bentall 1998). Fifth order amounts to being able to assert that "I *believe* that you *suppose* that I *think* that you *want* me to *believe* [that something is the case]" (where the successive intentional states are given in italics).

Since mentalizing appears to be cognitively demanding (and there is *some* very tentative evidence to suggest that achievable levels of intentionality might be related to frontal lobe volume: Dunbar 2003b), the fact that normal adults can regularly achieve fifth order is puzzling: when do we ever use such complex mentalizing abilities during the course of everyday social interaction? The simple answer would seem to be that everyday social situations do not require much more than third-order intentionality ("I *believe* that you *suppose* that John *thinks* . . ."). Fifth order seems an excessive price to pay when one could get away with a great deal less in terms of brain volume, given that brain is one of the most expensive of the body's tissues to maintain (Aiello and Wheeler 1995).

The most plausible explanation is that it is religion that requires fifth order. Table 15.1 gives what is effectively a task analysis of the mentalizing levels required for different kinds of religious beliefs. The important point to notice here is that we can have religion with anything more than, minimally, third-order intentionality. However, the *kind* of religion we have depends critically on the level of intentionality involved; third-order intentionality gives us what I would refer to as personal religion. The important issue is that fifth order is minimally necessary to make religion a genuinely communal activity, and the difference is critical. With third-order intentionality, I can try to convince you that there is a supernatural being who has some intentions, but there is neither obligation nor compulsion for you to believe me. A perfectly reasonable response on your part is simply to look at me askance. Only with fifth order is there sufficient purchase for me to be able to

TABLE 15.1. *An Intentionality Task Analysis of Religion*

LEVEL OF INTENTIONALITY	RELIGIOUS UTTERANCE POSSIBLE	FORM OF RELIGION
1	I <i>believe</i> that God [. . . exists].	None
2	I <i>believe</i> that God is <i>willing</i> [. . . to intervene if you disobey his laws].	Supernatural fact
3	I <i>intend</i> that you <i>believe</i> that God is <i>willing</i> [. . . to intervene].	Personal religion
4	I <i>intend</i> that you <i>believe</i> that I <i>want</i> God to be <i>willing</i> [. . . to intervene].	Social religion
5	I <i>intend</i> that you <i>believe</i> that God <i>understands</i> that I <i>want</i> him to be <i>willing</i> [. . . to intervene].	Communal religion

NOTE: Reproduced with permission from Dunbar (in press).

persuade you that you have to accept my view on this, because only at this point does the threat of divine intervention become part of an equation that you might be willing to accept.

In sum, then, with third-order intentionality, I can tell you what I believe sincerely to be the case, but I have no way of *making* you believe it just because I say it: this is simply my *personal* belief about how the world is. At fourth order, you can accept my view, but there is still no threat of external compulsion; religion at fourth-order intentionality is *social* because it will work *if* we can agree on it, but there is still no reason why I should agree with you. However, with fifth order, you are contractually aware that God exists as part of the bargain, and religion becomes *communal* because both of us know that each accepts the truth of the statement. In addition, a dimension of compulsion is added, because the threat of other-world intervention (or of dire consequences in the next world, even if you survive the present one unscathed) is one that is risky to ignore. We have no way of checking whether the threat of intervention is actually true (since it might happen in the next world after death), and that is a risk that we cannot afford to take—by the time you find out that I was right, it is too late to rectify your erroneous decision to ignore my demands.

This gives religion the kind of clout that is needed for it to function with sufficient threat to force you to toe the line. Other-world threats have

two advantages over real-world threats. First, the consequences can be expected to last a *very* long time (and we obviously have good folk-empirical evidence that the present real world has only limited duration: people die). Thus, the stakes are raised very considerably relative to the sticks-and-stones equivalent that can be offered in the here and now. Second, you have no way of checking the truth of my claim, so you have to take a considerable risk if you decide to ignore me. Since humans tend to be risk-averse, we may have a natural inclination to believe rather than not—just in case. Between the two, this raises the stakes very considerably. The effect is heightened by the fact that you are already committed to accepting part of the proposition in the fifth-order statement: we both believe that God exists, even if you need persuasion that he might exact a price for your behavior. Once you've agreed that God might exist, I'm home and dry and can put considerable pressure on you.

If religion is dependent on fifth-order intentionality, and achievable intentionality level is a function of brain size, then we ought to be able to map the trends in intentionality stages into the hominin fossil record, much as we did with group size and grooming time. Since achievable intentionality level maps best onto frontal lobe volume (Dunbar 2003b), it is mainly a matter of having an equation relating frontal lobe volume to cranial volume. Once again, this is fairly straightforward, given the fact that all brain

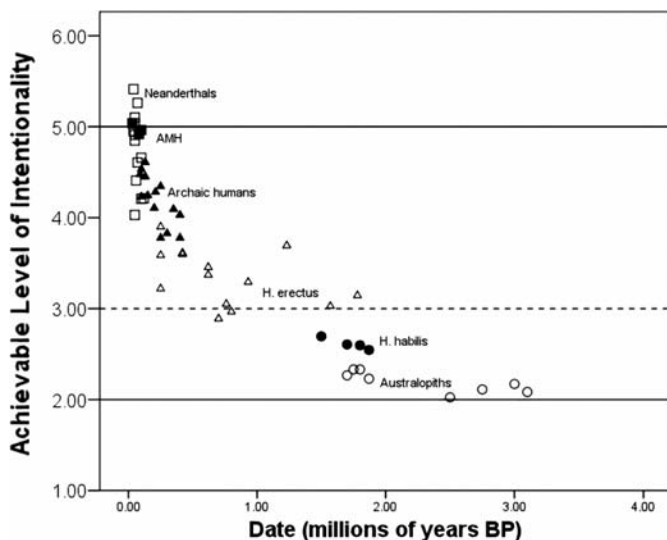


FIGURE 15.2 Maximum achievable levels of intentionality for individual hominid populations (defined as in figure 15.1). Intentional levels are predicted from brain volume using the equation given by Dunbar (2003b). Note that these intentionality levels differ from those given by Dunbar (2003a) by one order so as to correct for the omission of the subject's own intentional state in the original study.

components are strongly allometrically related to each other and to total brain size (Finlay and Darlington 1995). Mapping achievable levels of intentionality so determined onto the hominin fossil record (figure 15.2) suggests that fifth order is unlikely to have been achieved before the appearance of anatomically modern humans. Archaic humans, by contrast, would have been limited to fourth order and so are likely to have engaged in some form of religious activity but not in fully paid-up integrational religion.

The Neanderthals remain an interesting question in this context, since their large brains would imply a frontal lobe of at least modern human proportions (and certainly larger than those that characterize other archaic humans). This, of course, assumes that Neanderthals followed the same scaling relationships for brain size as everyone else. While it is, of course, true that these relationships are universal and do reliably apply universally, they are not without error variance around the regression lines. There are modest deviations away from the regression in many cases and quite substantial deviations in a few cases. Gorillas, for example, have a large total brain size, but they do not have a neocortex that is proportional to this. In fact, their neocortex is relatively small, in part because they have an unusually large cerebellum. The conspicuous Neanderthal occipital

“bun” (in the visual area of the brain) suggests that they might in fact have a frontal lobe that is rather smaller than might be anticipated. How much smaller is critical, but we have yet to explore this in any detail.

An additional prerequisite at this point is, of course, language. In the absence of language, we have no means of communicating our beliefs about the spirit world to each other. In effect, we are functionally limited to second-order intentionality at best, irrespective of whether one of us can imagine multiple layers of intentionality. We cannot come to agree on how to see the real and spirit worlds in relation to each other.

The grooming and anatomical evidence suggests that some form of vocal communication was in place by about 0.5 mya (the appearance of archaic humans). However, we cannot be certain that this was full grammatical language. One possible sequence might be that some form of chorusing (singing) evolved at 0.5 mya, with this evolving into fully grammatical language in anatomically modern humans around 0.25 mya. This would be supported by the claim that FOX2P gene (the “gene for language”) did not mutate from its ancestral chimpanzee-like form into its modern human form until about 0.2 mya (Enard et al. 2002). However, emphasizing the role of the FOX2P gene in grammatical language is at best tendentious. For example, it is clear that

it also influences other aspects of cognition besides the capacity to produce grammatically well-formed sentences.³ An alternative sequence might be that music appeared with the earlier *erectus* step-change at about 0.7 mya, and true language appeared at 0.5 mya; and if this sequence was correct, then we must infer that Neanderthals would have had grammatical language in an essentially modern form. Which of these is right is crucial to deciding whether full religion appeared in archaic humans (and hence was inherited by the Neanderthals) or only with modern humans at 0.25 mya. In my view, the latter provides a better fit to the data, but the first is not at present beyond the bounds of possibility.

CONCLUSION

I have argued that the evolution of large social groups in humans depended on finding novel solutions to the bonding problem. Failure to do so means that group sizes are unavoidably limited to those that can be supported by social grooming in the conventional primate manner (i.e., groups of about fifty to sixty individuals). I suggest that the pattern of hominin brain evolution suggests a series of phases, corresponding to the evolution of at least three separate bonding mechanisms (laughter, music, and religion), all of which exploit the capacity for endorphins to create a sense of groupishness among a set of individuals. Each seems to allow the glass ceiling on group size to be raised just a fraction above its preceding limit. We still have a long way to go to validate these suggestions, even though they receive some *prima facie* support. Validating the hypotheses will require both more detailed experimental work at the psychopharmacological and behavioral levels, and a more concerted attempt to identify key anatomical and/or material culture signatures for the various elements that we can search for in the archaeological record.

NOTES

1. The claim in respect of the hypoglossal canal has been questioned by Degusta, Gilbert, and Turner (1999). However, their criticism is

based on a rather odd confusion between means and variances. The fact that some individuals in two populations overlap does not allow us to infer that both populations must *ipso facto* share all their traits. The fundamental issue is, Do the species' mean values differ?

2. Note that in Dunbar (2003), the upper limit is given as fourth order, on the basis of the experimental study by Kinderman et al. (1998). However, Kinderman et al. omitted to include the subject's own perspective in the calculation, and the orders of intentionality in their data should all be increased by one (giving a correct value for the upper limit of fifth order, as shown by Stiller and Dunbar 2007).
3. Since this was written, FOXP2 has been more widely documented, in particular in the Neanderthals reinforcing the suggestion that it is involved in the production of speech rather than grammar.

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SIXTEEN

Testing Functional Hypotheses about Cross-Cultural Variation

A MAXIMUM-LIKELIHOOD COMPARATIVE ANALYSIS
OF INDO-EUROPEAN MARRIAGE PRACTICES

Laura Fortunato and Ruth Mace

BEHAVIORAL ECOLOGY is the branch of biology dealing with the study of animal behavioral variation within and across taxa; it addresses questions about the function of behavior, focusing on its survival value in relation to the environment (Tinbergen's [1963] "why" questions; Krebs and Davies 1993, 382). Human behavioral ecology investigates variation in human behavior, including cultural behavior, within and across societies (Winterhalder and Smith 2000).

Investigation into the function of behavior involves making hypotheses based on observations, deriving testable predictions from the hypotheses, and testing. Three strategies are available for testing functional hypotheses: examination of variation among individuals within a group, experiments, and examination of variation among groups (Krebs and Davies 1993, 24). Given that human behavior is generally not amenable to experimental manipulation, the study of human behavioral variation is largely restricted to comparison within and among groups.

In this chapter, we provide an example of the application of the behavioral ecology approach to the study of variation in cultural practices across groups, focusing on wealth transfers at marriage. In the first part, we review the observations that led to the evolutionary interpretation of these practices and previous analyses of their distribution; in the second part, we illustrate the use of a phylogenetic comparative method with data on wealth transfers at marriage in Indo-European groups.

THE CASE OF TRANSFERS OF WEALTH AT MARRIAGE

OBSERVATIONS AND HYPOTHESIS

The transfer of resources at marriage is a widespread practice; resources may be in the form of women, services, or property (Westermarck 1926, 156). Property may be transferred from the groom or his kin to the bride's kin (bride wealth) or to the bride (indirect dowry; Goody 1973, 2), or from the bride's kin to the bride (dowry).

Alternatively, the families of the spouses may exchange goods in reciprocation. These practices are not distributed evenly across world regions; dowry in particular is restricted to circum-Mediterranean and East Asian societies (Jackson and Romney 1973). What factors led to this uneven distribution?

Here we will investigate the hypothesis that practices of wealth transfer at marriage represent forms of sex-biased parental investment. Parental investment is defined as any investment in an individual offspring that increases his or her chance of surviving and reproducing. Given that parents have access to a limited pool of resources, this concomitantly reduces their ability to invest in other offspring (Trivers 1972, 139). Parental investment theory predicts that parents should allocate resources among their offspring in ways that maximize their own reproductive success. The observed distribution of wealth transfer practices should thus reflect some condition determining sex biases in parental investment.

Wealth correlates positively with reproductive success in traditional human societies in which property is individually owned (e.g., Irons 1979). In these societies, parents may influence the reproductive success of their offspring directly through the provision of resources to be invested in reproduction; this indirectly affects their own long-term reproductive outcome. Two observations indicate that wealth transfers at marriage may serve this purpose. Parents, and to a lesser extent other kin, are typically involved in their negotiation and provision (e.g., Lambiri-Dimaki 1985, 173), indicating that they have an interest in the outcome of marriage arrangements (cf. also Wiessner, this volume). The fact that the value of the transfer may be affected by the reproductive potential of the prospective spouse (e.g., Borgerhoff Mulder 1995) suggests that this shared interest may well be a reproductive one.

PREDICTIONS AND TESTS

Put crudely, the issue at stake is whether parents are on average more likely to increase their number of grandchildren by investing a given amount of wealth in the reproduction of their sons or

daughters (Gaulin and Boster 1990). In humans, as in other sexually reproducing species, males invest less in gametes than females and thus have higher potential reproductive rates; in these species, the variance in reproductive success is potentially greater among males than among females (Trivers 1972). It follows that parents investing their wealth in the reproduction of their sons will, on average, increase their number of grandchildren more than parents investing the same amount of wealth in the reproduction of their daughters (Hartung 1976).

Hartung (1982) predicted that this pattern would result in male biases in property allocation where marriage is polygynous. Fitting this prediction, he found a strong positive relationship between degree of polygyny and occurrence of bride wealth in Murdock's (1967) *Ethnographic Atlas*. In these codes, degree of polygyny is operationalized as no polygyny (polygyny not permitted or encouraged), limited polygyny (<20 percent of married males in polygynous unions), and general polygyny (>20 percent of married males in polygynous unions). For the 850 societies coded as practicing bride wealth or as characterized by the absence of significant considerations, bride wealth is present in 37.5 percent of societies with no polygyny, in 52.8 percent of societies with limited polygyny, and in 90.8 percent of societies with general polygyny.

Where polygyny is not allowed, however, the difference in variance in reproductive success between the sexes is reduced, as consequently is the benefit to parents of biasing investment toward the reproduction of their sons. Where the prohibition on polygynous marriage coincides with significant differences in status and resources among males, parents may more profitably use their wealth to gain access to the resources of high-status husbands for their daughters. Exclusive access to these resources may translate in greater reproductive success for their daughters and for their daughters' children. Gaulin and Boster (1990) argued that the provision of daughters with wealth at marriage may represent one of a number of strategies

employed in this competition. Dowry, for example, is commonly provided in hypergynous marriages (e.g., Dickemann 1979); accordingly, the occurrence of this practice should be most likely in nonpolygynous, stratified societies. Fitting this prediction, they found that in the *Ethnographic Atlas* dowry is most common in societies characterized by absence of polygyny and presence of stratification. They operationalized these variables as polygyny (limited or general) versus no polygyny (no polygyny/monogamy or polyandry) and as stratification versus no stratification. Dowry occurs in less than 1 percent of the 994 societies that are either polygynous or nonpolygynous but not stratified, and in 37.5 percent of the 72 stratified nonpolygynous societies, resulting in its being fifty times more common in the latter.

The models tested by Hartung (1982) and Gaulin and Boster (1990) perform equally well on subsets of the *Ethnographic Atlas*, including Murdock and White's (1969) *Standard Cross-Cultural Sample*. These subsets are devised to control for the effect of history on the distribution of cultural practices, an issue known in anthropology as "Galton's problem." For example, societies may share cultural traits by virtue of descending from a common ancestor; consequently, they may not be treated as independent data points in statistical analyses of the distribution of these traits. An approach commonly used to address this issue is to restrict the analyses to a sample of societies drawn widely across geographic regions or linguistic groups. The *Standard Cross-Cultural Sample*, for example, was obtained by dividing the *Ethnographic Atlas* into sets of societies that likely shared similarities through historical association and by subsequently choosing the most accurately described one from each set. This approach reduces the possibility that a society may be counted more than once because it was artificially subdivided. However, it simply moves the problem of historical relatedness back in time, while causing the loss of information on variation among closely related societies (Mace and Pagel 1994; Murdock and White 1969).

To address the issue in a principled way, Mace and Pagel (1994) proposed the application of phylogenetic comparative methods to the study of cross-cultural variation. These methods are used in evolutionary biology to control for the effect of historical relatedness among biological groups (species or higher taxa) on the outcome of comparative analyses. They test for the association of a phenotypic trait with another phenotypic trait or with an environmental variable on a phylogenetic model of the historical relationships among the groups (Felsenstein 1985; Harvey and Pagel 1991). The traits can be assumed to be related if they appear to change together in a number of independent occasions, as judged from the historical relationships among the groups and from the distribution of traits among them; this is taken as evidence that the traits may be functionally linked. Phylogenetic comparative methods assume vertical transmission of traits along the branches of a phylogeny. For the purpose of testing hypotheses about the function of cultural practices, this corresponds to assuming that cultural traits are transmitted from parent to daughter populations. Independent instances of change include the acquisition or loss of a trait, either by original invention or by copying from another culture; the latter corresponds to horizontal transmission across groups (Mace and Pagel 1994).

Here we illustrate the application of the phylogenetic comparative approach to testing hypotheses about the evolution of wealth transfers at marriage and marriage systems in Indo-European (IE) groups. Building on the findings by Hartung (1982) and Gaulin and Boster (1990), we predicted that bride wealth and dowry should evolve in correlated fashion with polygynous and monogamous marriage, and that changes in wealth transfer practices should reflect changes in marriage systems. We investigated the association of these traits using a likelihood-based phylogenetic comparative method on cross-cultural data. The cross-cultural data were mapped onto a phylogenetic tree obtained from linguistic data, which served as a model of the historical relationships among the groups in the sample.

DATA AND METHODS

COLLATING THE CROSS-CULTURAL DATA SET

We collated the comparative data by matching speech varieties in Dyen, Kruskal, and Black's (1992) IE basic vocabulary database with societies in Gray (1999), in Levinson (1994), and in primary ethnographic sources. We then used data from the linguistic database to generate a phylogenetic tree for the groups in the sample, as described later. We included in the analyses only groups for which we found evidence for both wealth transfer practice and marriage system.

We coded societies as polygynous or monogamous based on the sanctioned form of marriage. In the model under investigation, dowry is used to gain exclusive access to the resources of, rather than exclusive sexual access to, high-status husbands; we reasoned that, since monogamous marriage is usually associated with "monogamous resource flow" (Gaulin and Boster 1997, 374), it would not matter whether monogamous marriage did not coincide with monogamous mating.

We coded societies as practicing bride wealth or dowry based on the direction of the parental investment (transfer from groom's versus transfer from bride's kin). We preferred the preindustrial pattern for groups that recently ceased the traditional practice of transferring wealth at marriage, and we coded groups with evidence of both practices based on the prevalent mode of transfer (e.g., we preferred the form in variable 6—primary mode of marriage—to the form in variable 7—alternate mode of marriage—in Gray 1999).

We coded the outgroup Hittite as practicing monogamy and dowry based on the information contained in the Hittite code of laws, a compendium of approximately two hundred clauses dating back to at least 1650 BCE (Bryce 2002, 34), as reported in Gurney (1975) and Bryce (2002). The lack of reference to multiple spouses in any clause of the code suggests that only monogamous marriages were legally sanctioned. In particular, the rights and obligations specified by the large number of clauses dealing with marriage provisions, including the detailed

accounts of the property and inheritance rights of marriage partners and their offspring, only applied to officially recognized monogamous unions (Bryce 2002, 132–133).

Hittite marriage was accompanied by a symbolic gift generally referred to as bride wealth (*kusata*) and by a substantial dowry (*iwaru*) (Bryce 2002, 120; Gurney 1975, 100). *Kusata* marriage was used to formalize unions between slave and free: it was required in order for the free partner to retain free status and for the descendants to acquire it. Accordingly, it was provided by a male slave marrying a free woman and by the father of the bride when a free man married into a slave family (Bryce 2002, 121–124). As such, *kusata* is not bride wealth in the strict sense, nor does it fit with either category of sex-biased parental investment.

OBTAINING A MODEL OF POPULATION HISTORY

The IE basic vocabulary database includes the forms of the meanings in the Swadesh two-hundred-word list of items of basic vocabulary for ninety-five modern IE speech varieties (languages, dialects, and creoles), classified into cognate classes; two or more forms of a meaning are cognate if they share a common origin. The Swadesh lists consist of items of cross-culturally universal vocabulary such as pronouns, body parts, and numerals, that are less prone to innovation and borrowing than other meanings.

M. Pagel provided the coded linguistic data matrix, including data for Hittite. Hittite belongs to the extinct monophyletic sister group to the IE clade, the Anatolian languages; these two clades together form the Indo-Hittite language family (Rexová, Frynta, and Zrzavý 2003). We used Hittite as the outgroup for rooting the tree.

We generated the phylogenetic tree using a maximum-parsimony optimality criterion, as implemented by PAUP* 4.ob4a (Swofford 2002), on the linguistic data for the varieties associated with the fifty-two groups included in the cross-cultural sample. Meanings were coded

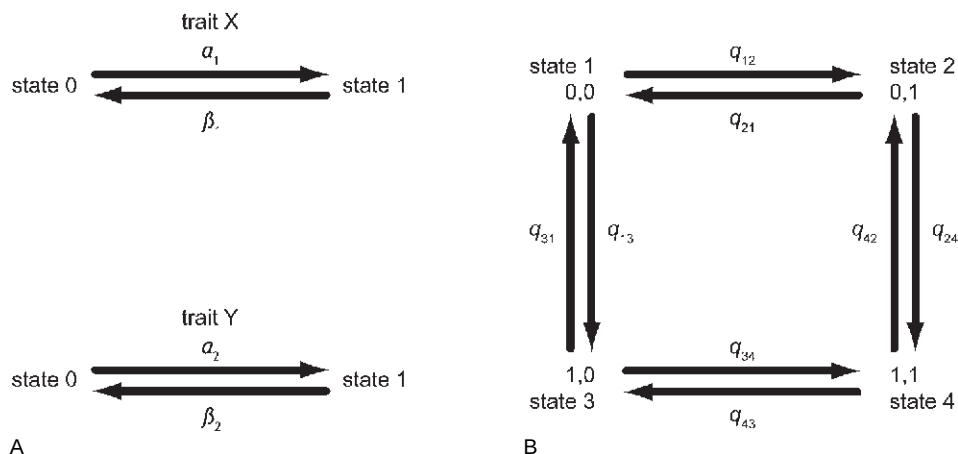


FIGURE 16.1 Models of evolution for two binary traits X and Y taking states 0/1. (a) Model of independent evolution I: each of the two traits X and Y is allowed to change independently of the other. α and β represent the estimated rates of change, which are used to obtain the probability of change for each trait. (b) Model of dependent evolution D: the probability of change for one trait depends on the state of the other trait. The four states represent the possible combinations of character states for X, Y; diagonal transitions are not permitted, implying that only one trait is allowed to change at any one time. The possible transitions are described by eight transition rate parameters represented as q_{ij} , which are used to estimate the probability of each transition. Subscripts to q denote transitions from state i to state j (e.g., q_{12} is the rate parameter for transitions from state 1 (0, 0) to state 2 (0, 1)—i.e. changes in trait Y from 0 to 1 when trait X is 0).

as multistate, with each state representing a cognate class. Character states were unordered, and multiple character states for a variety were treated as uncertainty. We used a heuristic strategy to search for the optimal tree or set of trees, running one thousand replications of tree bisection-reconnection (TBR) with random addition sequence, storing up to two thousand trees in memory per search.

We performed an initial search with all characters having equal weights; based on this search, we then assigned weights to the characters through a posteriori successive approximations (Farris 1969). We conducted the consecutive heuristic searches with the new weights performing one thousand replications of TBR with random addition sequence, again storing up to two thousand trees in memory. We used bootstrap analysis of the weighted characters to estimate the support for the individual clades on the tree obtained with this procedure, using heuristic searches with twenty TBR random addition sequence replicates on five hundred bootstrap samples.

TESTING HYPOTHESES ABOUT EVOLUTION

We used the likelihood-based method for the comparative analysis of binary traits described in Pagel (1994, 1997), implemented by the program Discrete.

The method consists in fitting statistical models of the way the traits may have evolved to the comparative data mapped onto a phylogeny, using maximum likelihood to estimate the likelihood of producing the observed data under each model. It works by reconstructing the evolution of the two traits to make the observed distribution of character states most likely, given a model of the historical relationships among the taxa and a statistical model of the way evolution proceeds (Pagel 1994, 1999).

We initially fitted a model of independent evolution I, under which each trait changes between its two character states independently of the other, and a model of dependent evolution D, under which changes in character state for the two traits are interdependent (figure 16.1). By fitting alternative versions of these models to the data, we tested hypotheses on the probable

direction of change from the estimated ancestral state, on the relative ordering of changes, and on the most likely route of evolution of the traits, as described in Pagel (1994). The alternative models are obtained by restricting one or more parameters in models I and D to be equal to each other or to arbitrary values. Discrete estimates the probability of ancestral states at internal nodes on the phylogeny as described in Pagel (1999).

We used likelihood ratio (LR) tests to assess whether pairs of likelihood values obtained under alternative models differed significantly. Significant differences indicate that the model resulting in the higher value is more likely to have produced the observed data; this suggests that it is a better description of the way the two traits have evolved.

We fitted parameter κ by maximum likelihood for all models; κ stabilizes the results across runs by smoothing the likelihood surface where fitting likelihood models proves difficult—for example, for trees with a large range of branch lengths (Pagel 1994). We repeated all analyses a minimum of three times, and in all cases results were stable across runs; here we report the highest values for each set of analyses.

RESULTS

TREE BUILDING

Unweighted parsimony yielded a set of 252 optimal trees with tree length 3,372.00, consistency index $CI = 0.9001$, retention index $RI = 0.8966$, and rescaled consistency index $RC = 0.8075$. After weighting the characters, three searches were necessary for two consecutive ones to converge on the same tree and for the character weights to remain unchanged; the optimal tree had tree length 2711.83, $CI = 0.9152$, $RI = 0.9129$, and $RC = 0.8361$ (figure 16.2). Figure 16.3 shows the 50 percent majority-rule consensus tree for the bootstrap sample of trees obtained from the weighted data set.

We computed the CIs for the 187 parsimony-informative characters. This statistic measures

the level of character fit on the tree; the high values indicate a predominantly branching pattern of evolution for IE basic vocabulary. This suggests that horizontal transmission of items of basic vocabulary is limited in IE languages; consequently, a tree model is an appropriate representation of the historical relationships among them.

The commonly recognized elementary IE clades (Celtic, Romance, Germanic, Albanian, Indic, Iranian) received bootstrap support >90 percent, as did the Balto-Slavonic and Indo-Iranian clades (figure 16.3); these groups were all monophyletic. Higher-level groups received lower support, reflecting the failure of comparative linguistics to untangle the pattern of relationship among them.

These results are highly consistent with those obtained by Rexová et al. (2003) using unweighted parsimony on a subset of the IE basic vocabulary database including eighty-four speech varieties, with Hittite as the outgroup. These, in turn, are highly consistent with traditional IE classification, which suggests that our tree represents an adequate model of the relationships among IE groups for use in the comparative analyses.

COMPARATIVE ANALYSES

Figure 16.4 shows the geographic distribution of societies in the sample. The cultural traits are highly clustered, both geographically and on the phylogeny (figures 16.2 and 16.4), emphasizing the need to use a phylogenetic comparative approach.

The log-likelihood of the independent model of evolution I is significantly lower than the log-likelihood of the eight-parameter dependent model D, indicating that wealth transfer practices and marriage systems evolve in correlated fashion (omnibus test, table 16.1). The four states in model D are bride wealth with polygyny (state 1: 0, 0), bride wealth with monogamy (state 2: 0, 1), dowry with polygyny (state 3: 1, 0), and dowry with monogamy (state 4: 1, 1) (figure 16.5). Estimation of the ancestral state at the root indicates the latter as most likely, with probability 0.86.

We performed the tests in table 16.1 to determine the most likely route of evolution of the

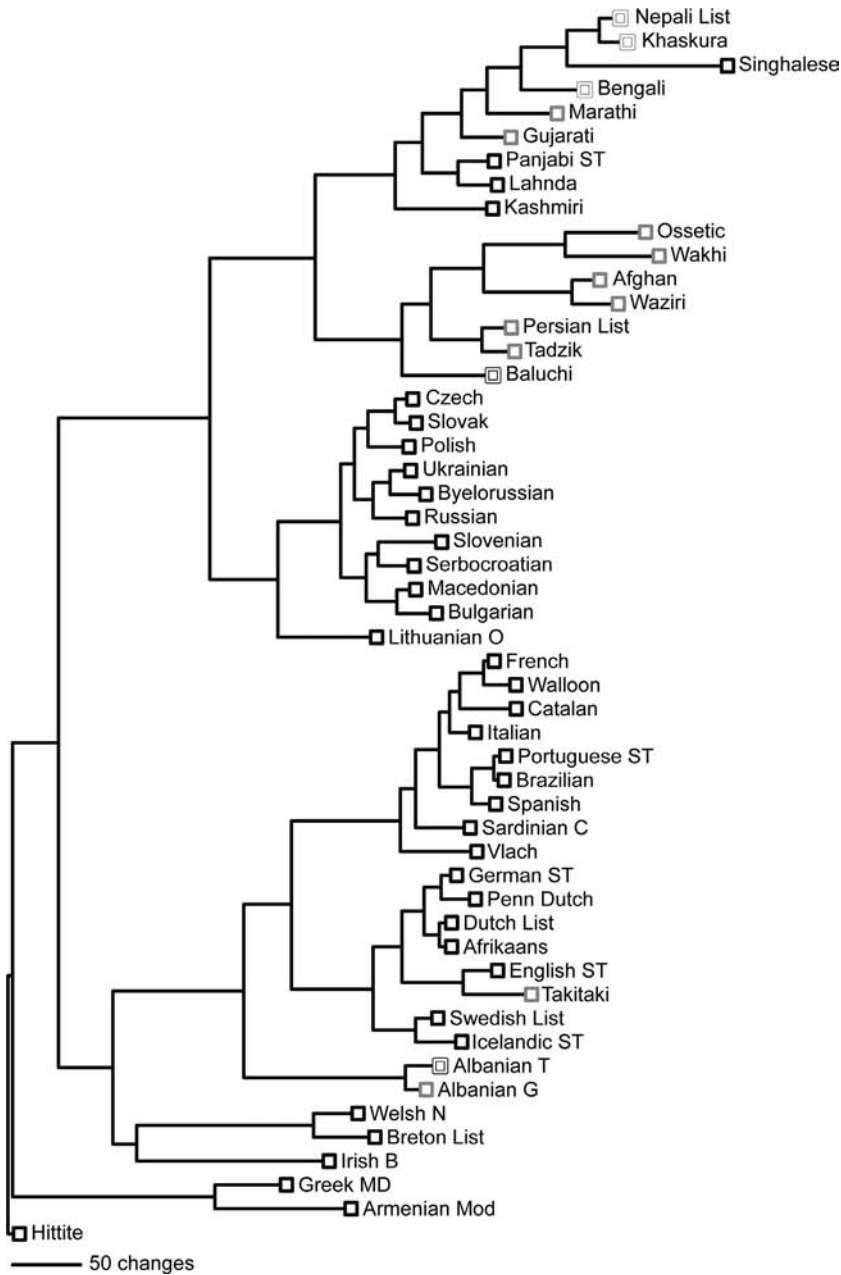


FIGURE 16.2 RC weighted parsimony tree of IE speech varieties (plus the outgroup Hittite). The tips are labeled with wealth transfer and marriage system practice for the groups associated with the speech varieties. Solid gray: bride wealth with polygyny; outline gray: dowry with polygyny; outline black: bride wealth with monogamy; solid black: dowry with monogamy.

two traits from the ancestral state. The eight alternative model tests indicate that the transitions specified by rates q_{12} , q_{24} , q_{31} , q_{43} do not differ significantly from zero, leaving a minimum model with parameters q_{13} , q_{21} , q_{34} , q_{42}

(figure 16.5). The flow diagram suggests that both bride wealth with polygyny (state 1: o, o) and dowry with monogamy (state 4: 1, 1) are relatively stable: of the four transitions in the minimum model differing significantly from

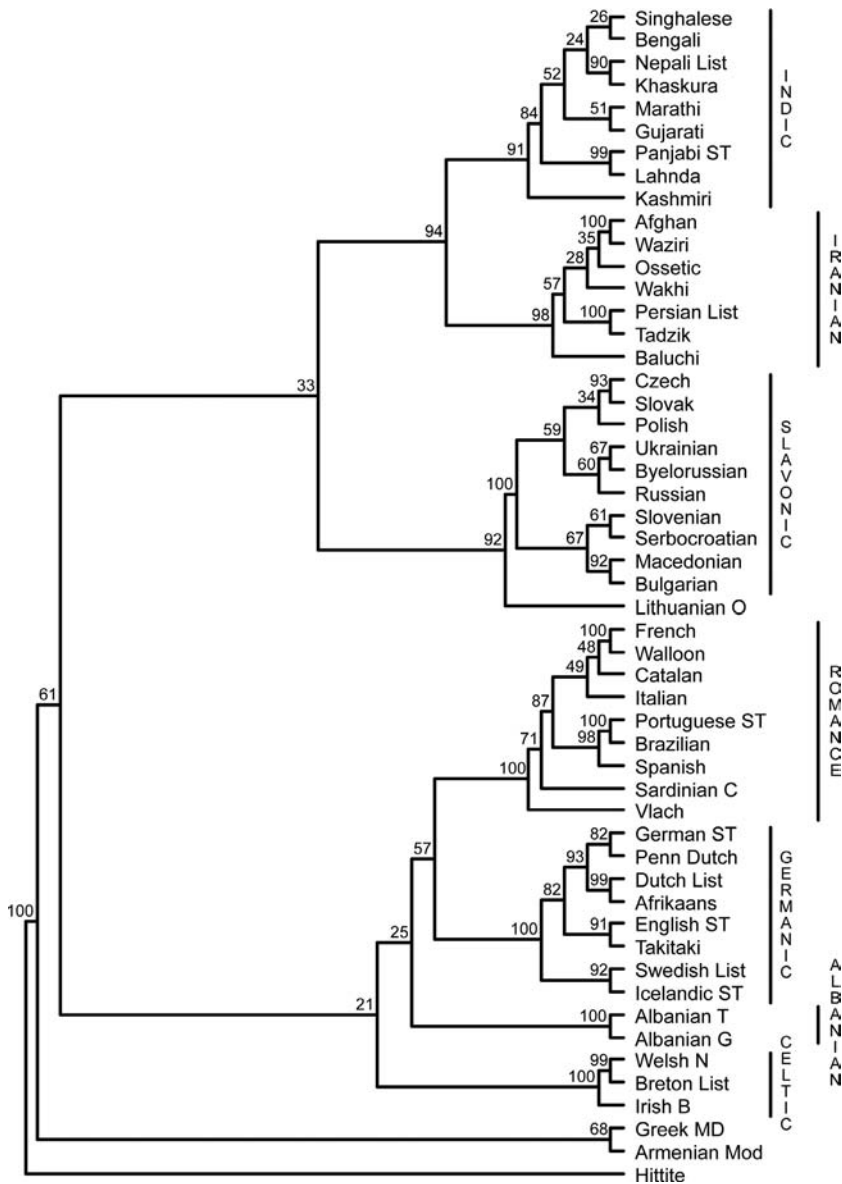


FIGURE 16.3 Bootstrap 50 percent majority-rule consensus tree of IE speech varieties (plus the outgroup Hittite). Compatible groups found in less than 50 percent of the trees are also included; the actual number of trees out of one hundred in which a clade appears is reported at each node.

zero, the two leading to these states (q_{21} and q_{34} , respectively) are specified by rates one order of magnitude larger than the two leaving them (q_{13} and q_{42} , respectively). It follows that the transitions leading to bride wealth with monogamy (state 2: o, 1) and to dowry with polygyny (state 3: 1, o) are specified by rates (q_{42} and q_{13} , respec-

tively) one order of magnitude smaller than the two leaving them (q_{21} and q_{34} , respectively), making these states relatively unstable. The values of the transition rate parameters are shown in figure 16.5.

Contingent change tests indicate that the occurrence of changes from monogamy to

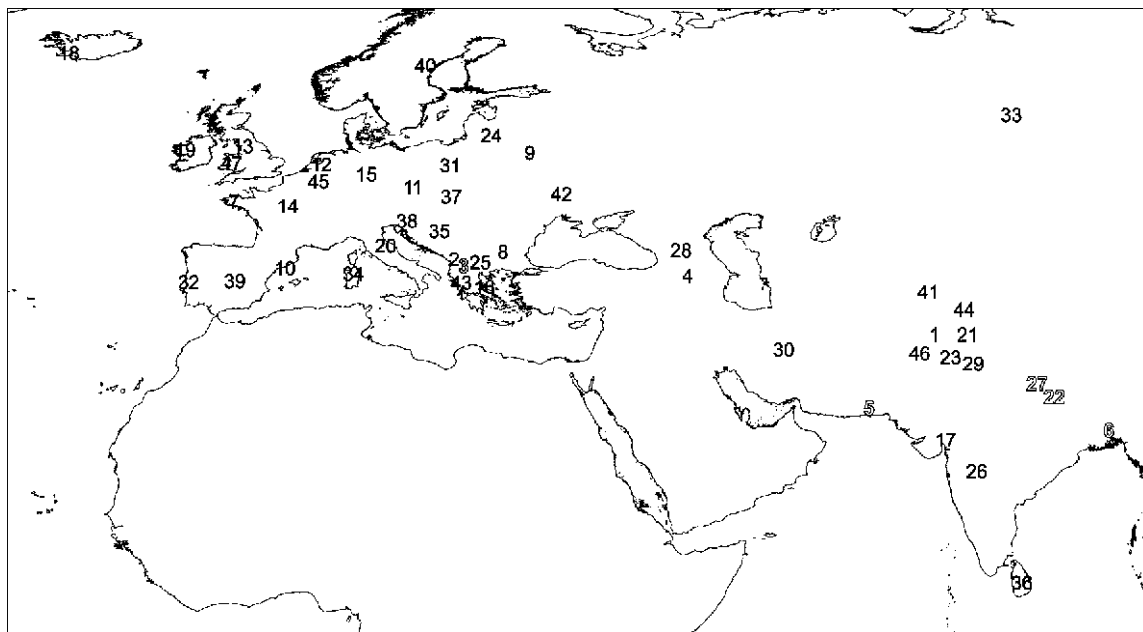


FIGURE 16.4 Geographic distribution of the speech varieties associated with groups in the cross-cultural sample. Locations represent the midpoint of the language area, based on data from Gordon (2005). Labels indicate wealth transfer and marriage system practice for the groups associated with the speech varieties. Solid gray: bride wealth with polygyny; outline gray: dowry with polygyny; outline black: bride wealth with monogamy; solid black: dowry with monogamy. 1, Afghan; 2, Albanian G; 3, Albanian T; 4, Armenian Mod; 5, Baluchi; 6, Bengali; 7, Breton List; 8, Bulgarian; 9, Byelorussian; 10, Catalan; 11, Czech; 12, Dutch List; 13, English ST; 14, French; 15, German ST; 16, Greek MD; 17, Gujarati; 18, Icelandic ST; 19, Irish B; 20, Italian; 21, Kashmiri; 22, Khaskura; 23, Lahnda; 24, Lithuanian O; 25, Macedonian; 26, Marathi; 27, Nepali List; 28, Ossetic; 29, Panjabi ST; 30, Persian List; 31, Polish; 32, Portuguese ST; 33, Russian; 34, Sardinian C; 35, Serbocroatian; 36, Singhalese; 37, Slovak; 38, Slovenian; 39, Spanish; 40, Swedish List; 41, Tadziki; 42, Ukrainian; 43, Vlach; 44, Wakhi; 45, Walloon; 46, Waziri; 47, Welsh N.

polygyny is contingent on wealth transfer practice, as setting $q_{21} = q_{43}$ significantly reduces the likelihood of the model. In model D, q_{43} does not differ significantly from zero, indicating that changes from monogamy to polygyny in the presence of dowry are highly unlikely.

Temporal order/relative rate tests indicate that changes from bride wealth to dowry and from polygyny to monogamy occur in no specific order, whereas changes from dowry to bride wealth and from monogamy to polygyny occur at different relative rates, as setting $q_{42} = q_{43}$ significantly reduces the likelihood. In model D $q_{42} \gg q_{43}$, indicating that changes from dowry to bride wealth are likely to precede changes from monogamy to polygyny.

These results indicate that wealth transfer practices and marriage systems evolve in corre-

lated fashion in IE groups. Furthermore, they suggest that changes from monogamy to polygyny are contingent on wealth transfer practice and never occur in the presence of dowry; accordingly, changes from dowry to bride wealth precede changes from monogamy to polygyny. The most likely pathway of coevolution for these traits can be summarized as follows (figure 16.5). First, a transition occurred from the ancestral state of dowry with monogamy to bride wealth with monogamy (specified by q_{42}). Polygyny was then rapidly acquired by groups in which this transition had taken place, with the preservation of bride wealth as wealth transfer practice (transition specified by q_{21}). Only transitions to dowry with polygyny (specified by q_{13}) occurred from this state, which, however, rapidly reverted to dowry with monogamy (transition specified by q_{34}).

TABLE 16.1 . Comparison of Likelihood Values for Alternative Models of Evolution of Wealth Transfer Practices and Marriage Systems in IE Groups

TEST (D.F.) ^{a, b}	HYPOTHESIS ^a	DESCRIPTION ^{a, c}	LOG-LIKELIHOOD ^d	IR ^d	P
Omnibus (4)	I < D	Correlated evolution	log(l) = -35.95	9.38	0.0009
Alternative model (1)	$q_{12} = 0$	Transition q_{12} excluded	log(D ₇) = -26.82	0.50	n.s.
	$q_{13} = 0$	Transition q_{13} excluded	log(D ₇) = -28.65	4.17	0.0413
	$q_{21} = 0$	Transition q_{21} excluded	log(D ₇) = -30.21	7.28	0.0070
	$q_{24} = 0$	Transition q_{24} excluded	log(D ₇) = -26.76	0.39	n.s.
	$q_{31} = 0$	Transition q_{31} excluded	log(D ₇) = -26.79	0.44	n.s.
	$q_{34} = 0$	Transition q_{34} excluded	log(D ₇) = -28.64	4.15	0.0416
	$q_{42} = 0$	Transition q_{42} excluded	log(D ₇) = -28.94	4.75	0.0294
	$q_{43} = 0$	Transition q_{43} excluded	log(D ₇) = -26.57	0.00	n.s.
Minimum model (4)	$q_{12} = q_{24} = q_{31} = q_{43} = 0$	Transitions q_{12} , q_{24} , q_{31} , q_{43} excluded	log(D ₄) = -26.57	0.00	n.s.
Contingent change (1)	$q_{12} \neq q_{34}$	Change polygyny → monogamy depends on state of wealth transfer	log(D ₇) = -26.95	0.77	n.s.
	$q_{21} \neq q_{43}$	Change monogamy → polygyny depends on state of wealth transfer	log(D ₇) = -30.89	8.64	0.0033
	$q_{13} \neq q_{24}$	Change bride wealth → dowry depends on state of marriage system	log(D ₇) = -26.72	0.30	n.s.
	$q_{31} \neq q_{42}$	Change dowry → bride wealth depends on state of marriage system	log(D ₇) = -26.70	0.27	n.s.
	$q_{12} \neq q_{13}$	Order of change polygyny → monogamy vs. bride wealth → dowry	log(D ₇) = -26.98	0.83	n.s.
	$q_{42} \neq q_{43}$	Order of change dowry → bride wealth vs. monogamy → polygyny	log(D ₇) = -28.60	4.07	0.0438
Temporal order/ relative rate (1)					

^aRefer to Pagel (1994) for details.

^bThe degrees of freedom (d.f.) correspond to the difference between the number of parameters of the two models being compared.

^cThe four states in the dependent model are bride wealth with polygyny (state 1: 0, 0), bride wealth with monogamy (state 2: 0, 1), dowry with polygyny (state 3: 1, 0), and dowry with monogamy (state 4: 1, 1).

^d q_i and D_i represent the likelihoods of the four-parameter-independent model and of the n -parameter-dependent model, respectively. The log-likelihoods are compared to the log-likelihood of the eight-parameter-dependent model D, log(D) = -26.57.

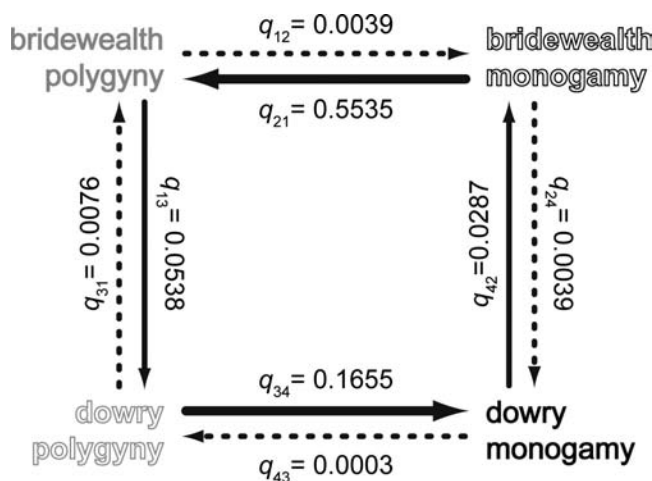


FIGURE 16.5 Flow diagram of the most likely pathway for the coevolution of wealth transfer practices and marriage systems in IE groups. The different letter types for the four states follow the coding scheme used in figures 16.2 and 16.4. Thick arrows represent rate transitions one order of magnitude larger than thin ones; dashed arrows represent rate transitions not significantly different from zero.

DISCUSSION

The difference between male and female reproductive potential plays a major role in determining animal mating and parenting strategies. Extending this framework to human cultural behavior, cross-cultural variation in marriage practices may be partly understood in terms of this difference. Transfers of wealth at marriage, for example, may be viewed as tools used by parents to influence the reproductive success of their offspring, while ultimately attempting to maximize their own reproductive outcome. Parents should use bride wealth to have their sons marry polygynously where polygyny is allowed, and dowry to have their daughters' children born into high-status families where it is not (Hartung 1997, 344). In line with these predictions, bride wealth is most common where the degree of polygyny is highest (Hartung 1982), and dowry is most common where the prohibition on polygynous marriage coincides with stratification (Gaulin and Boster 1990).

By applying the phylogenetic comparative approach to cross-cultural data, we showed that in IE groups the association of bride wealth with polygyny and of dowry with monogamy is not an artifact of historical relatedness; rather, wealth transfer practices and marriage systems evolve in correlated fashion, suggesting that they may be functionally related. Our model

indicates that dowry with monogamy represents the most likely ancestral state; this finding is supported by estimation of the diachronic development of bride wealth and dowry in IE groups (Fortunato, Holden, and Mace 2006). Reconstruction of the most likely pathway of evolution from the ancestral state indicates that bride wealth with polygyny and dowry with monogamy represent relatively stable states in the coevolution of these practices. The other possible combinations of traits—bride wealth with monogamy and dowry with polygyny—are instead relatively unstable. As noted earlier, a prohibition on polygynous marriage greatly reduces the difference in variance in reproductive success between male and female offspring, and consequently any benefit to parents of investing preferentially in their sons. Conversely, in polygynous societies, the benefit to parents of securing daughters with access to the resources of high-status husbands is offset by the dilution of those resources among multiple wives.

In the theoretical model for nonhuman species, the mating system brings into effect the potential difference in within-sex variance in reproductive success between males and females, which in turn determines patterns of parental investment; based on this model, we predicted that changes in marriage systems would drive changes in wealth transfer practices. The results suggest, however, that in IE

groups changes in marriage systems reflect changes in wealth transfer practices.

An alternative explanation for this pattern may be derived from models that view human social groups primarily as units of production rather than reproduction. Goody (1976), for example, suggested that in Eurasia the advent of advanced agriculture through irrigation and plowing led to scarcity of land, caused by the increase in land productivity and exploitation, on the one hand, and by the population expansion these allowed, on the other. The tendency to keep scarce resources within the productive unit, usually the nuclear family, led to the crystallization of status differences based on resource control and to the emphasis of vertical transmission of property to maintain this status differentiation. Direct vertical transmission from parents to children resulted in the provision of daughters as well as of sons, as opposed to “homogenous transmission” to collateral kin where direct heirs of the same sex as the endower were not available. This “diverging devolution” of property took the form of both inheritance and dowry for daughters; dowry in particular served as a way to control their status through marriage to husbands of appropriate standing (Goody 1976, 20).

Goody (1976) tested the theory through path analysis of the *Ethnographic Atlas*; in the resulting model, advanced agriculture and stratification are causally linked to diverging devolution, which is in turn causally linked to the occurrence of marriage-related practices such as father’s brother’s daughter marriage, endogamy, prohibition on premarital sex, and monogamy (29). According to Goody (1976), this system of property distribution involved the commitment of property from both spouses to the establishment of some type of conjugal fund, which required matching of the dowry with property from the husband; this restricted the ability of men to enter multiple marriages, leading to a shift from polygynous to monogamous marriage (51, 109). Testing of this model using the phylogenetic comparative approach will be necessary to determine whether the observed relationships be-

tween wealth transfer practices and marriage systems evolved in response to the relative advantage—productive, reproductive, or both—offered by certain combinations of traits over others.

METHODOLOGICAL ISSUES

We have illustrated how the framework used to test functional hypotheses about animal behavioral variation can be applied to the study of human cultural behavior. In particular, we focused on the application of phylogenetic comparative methods to the study of variation in cultural practices. Here we briefly address some methodological issues, while acknowledging the need to replicate our analyses with both better methods and data.

In the comparative analyses, we used a phylogenetic tree to model the historical relationships among the groups in the sample. By definition, a phylogeny represents a hypothesis about the historical relationships among the groups under study, and it is a well-known problem of the phylogenetic comparative approach that results may be affected by the phylogeny used (e.g., Martins and Housworth 2002). As recognized by the first advocates of this approach in evolutionary biology, however, not using an explicit model of population history corresponds to implicitly assuming that the groups under investigation are equally related to one another (Felsenstein 1985); this seems a worse approximation of the past than a properly constructed phylogeny, for biological and human groups alike. Furthermore, in recent years, phylogenetic inference has moved toward statistical approaches that simultaneously provide an estimate of phylogenetic relationships and quantify the uncertainty in the estimation (Bayesian MCMC inference, reviewed in Huelsenbeck et al. 2001; Holder and Lewis 2003). This has spurred the development of phylogenetic comparative methods that take into account the uncertainty in the estimation of both the phylogenetic relationships and the parameters of interest to the comparative questions (e.g., Huelsenbeck and Rannala 2003; Pagel and Meade 2005, 2006; Pagel, Meade, and Barker

2004). The application of these methods to the comparative analysis of cultural practices (e.g., Fortunato et al. 2006; Pagel and Meade 2005) offers a promising framework for testing functional hypothesis about human behavior.¹

Given the limited scope for experimental manipulation in studies of human behavior, comparative analyses are likely to play an increasingly important role in understanding human cultural variation. We feel it is therefore worth noting a general limitation of the comparative approach that extends to phylogenetic methods. Comparative methods ultimately look for correlation between pairs of traits; correlation is taken as evidence that selection repeatedly converged on the same solution to a problem, suggesting that that solution conveys a relative advantage. However, selection may be acting on a third trait that is causally linked to one or both of the traits under investigation. Possible candidates for the study of human marriage practices include, for example, type of subsistence and degree of societal stratification, which determine patterns of property distribution in Goody's (1976) model. As for any method based on correlational evidence, there is no simple way to address this issue. One possibility to discriminate between alternative hypotheses is to look for independent support across different samples and to use the results of comparative analyses in conjunction with other approaches. For the purpose of cross-cultural research, these may include studies of variation within groups (e.g., Borgerhoff Mulder 1995) and systematic analyses of the diachronic development of cultural practices (e.g., Fortunato et al. 2006).

Of course, the difficulties of cross-cultural research also extend to the phylogenetic comparative analysis of cultural traits. These difficulties (reviewed in Levinson and Malone 1980, 9–15) mainly stem from the need to extrapolate discrete variables from complex cultural phenomena, a simplification most anthropologists seem unwilling to take responsibility for. This may partly explain why, despite its long history—Edward B. Tylor (1889) pioneered the quantitative study of cross-cultural data in

1888—cross-cultural research has played a minor role in anthropology compared with the role played by comparative analysis in evolutionary biology. With Hartung (1983, 125), we feel anthropologists should be “willing to test [a] less than perfect hypothesis with less than perfect data” and, we may add, with less than perfect methods, if anthropology is to be promoted to the rank of science. Methods, data and hypotheses can all be perfected where made explicit.

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NOTE

1. Nunn, Borgerhoff Mulder, and Langley (2006) used computer simulation to assess the ability of the method of phylogenetic independent contrasts (Felsenstein 1985) to correctly infer patterns of evolution under different modes of trait transmission across societies. Results indicate that when traits are not correlated and are transmitted vertically (i.e., from parent to daughter populations), Type I error rates are not significantly different from the expected value for the phylogenetic method, whereas they are highly inflated if phylogenetic relationships are not taken into account; in both cases, Type I error rates increase with increasing probability of horizontal transmission (i.e., copying a trait from another population). When traits are correlated, increasing probability of horizontal transmission causes the statistical power of both tests to increase (i.e., lower Type II error rate) at intermediate levels of correlation and to decrease (i.e., higher Type II error rate) at high levels of correlation. According to Nunn et al. (2006), and to one reviewer of this chapter, application of the phylogenetic comparative approach to cross-cultural data is therefore only appropriate when traits are transmitted across societies in

a strictly vertical fashion. However, given that *both* methods are sensitive to horizontal transmission, the phylogenetic comparative framework seems preferable to approaches that do not take phylogeny into account, at least until the development of methods that are robust to mode of trait transmission.

With regard to our analyses, empirical studies of trait transmission across societies have shown that traits relating to family and kinship, including marriage practices, are transmitted vertically (e.g., Guglielmino et al. 1995). Furthermore, it seems premature to extend Nunn et al.'s (2006) results to any application of the phylogenetic approach to cross-cultural data. The method of phylogenetic independent contrasts uses continuous data, a Brownian model of trait evolution, and works by reconstructing a unique set of ancestral states at the internal nodes of a phylogeny to be used for comparative hypothesis testing; the likelihood-based method uses discrete data, a Markov model of trait evolution, and was developed specifically to avoid treating an inferred set of states as actual observed data (Pagel 1994). These differences may well affect the sensitivity of each method to horizontal transmission (Mace and Pagel 1997, 307).

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SEVENTEEN

Parent–Offspring Conflict in Marriage

IMPLICATIONS FOR SOCIAL EVOLUTION AND MATERIAL CULTURE
AMONG THE JU/'HOANSI BUSHMEN

Polly Wiessner

IN 1875, T. SMILES wrote, “‘Marriage is a lottery?’ Well, it may be so but only if we abjure all the teachings of prudence.” In anthropology, prudence has been attributed to both biological preferences and cultural conventions. Biological approaches to mate choice emphasize factors that may be indicators of reproductive potential and ability to invest in offspring—namely, beauty in females and status in males (Brase 2006; Buss and Barnes 1986; Grammar 1993; Thornhill and Gangestad 2005). In these studies, it is assumed that individuals choose their mates and others have little say in the matter. In contrast, cultural approaches have often turned to formal models in which women are exchanged by men as objects and circulate to create certain desired social and political configurations (Dumont 1971; Lévi-Strauss 1969).

The truth lies somewhere between. In the majority of human societies, marriage is no simple matter. Rather, timing of marriage and choice of mates generate conflict between parents and offspring. Children seek prospective spouses with personal qualities that attract and stand to increase their individual reproductive success.

Parents are more concerned with factors that benefit all of their offspring and those of close collaterals. These include (1) recruiting labor for the broader kin group, (2) controlling the inheritance of land and other resources, and (3) constructing far-flung social ties of mutual obligation. Because marriage provides the backbone for many social institutions, who chooses marriage partners has enormous implications for understanding human societies. In view of this, it is surprising that the theory of parent–offspring conflict first proposed by Trivers (1974) has not been extended to marriage, though it has been used very productively for examining strategies in other stages of the life cycle (Fouts, Hewlett, and Lamb 2005; Haig 1993; McDade 2001; Kushnick, Nadapdap, and Raharto 2004; Wells 2003).

Here I will take data from the Ju/'hoansi (!Kung) Bushmen, foragers of Botswana and Namibia, to address the following questions:

1. What are the goals and preferences of Ju/'hoansi parents in arranging marriages?
2. What are children's goals and preferences in marriage?

3. Is there parent–child conflict around marriage? How great is it?
4. What are the outcomes for Ju/'hoan society when the parents win and when the children win?
5. What is the impact of arranged marriages on material culture?
6. What are the broader implications of who wins in parent–offspring conflict for social evolution?

The data I will use come from a number of sources. The first is twenty-five intensive interviews on marriage conducted in July–August 2005 with Ju/'hoansi born before 1945. This data set contains detailed information on the marriages of thirty-nine women and twenty-two men. The second comes from the demographic interviews conducted by Claire Ritchie and John Marshall in the mid-1980s and from the Marshall family records. These records have been entered into an electronic format and updated to 2004 to create a database of more than eight thousand individuals that covers the population of Nyae Nyae for the better part of the twentieth century. The third comes from my observations on marriage from my fieldwork between 1974 and 2005. All data presented here are from preliminary analyses; for the Ritchie/Marshall sample, only analysis of the data for women is complete; work on men is in progress.¹

THE JU/'HOANSI (!KUNG BUSHMEN)

The Ju/'hoansi are foragers of the Kalahari desert who, until the 1960s and 1970s, lived primarily from hunting some twenty-five species of animals and gathering more than one hundred species of wild plant foods (Biesele 1993; Lee 1979; Lee and DeVore 1968; Marshall 1976; Shostak 1981; Wilmsen 1989a). Men devoted much of their time to hunting and women to foraging, though men helped in foraging efforts and women collected small animals. In the past, the Ju/'hoansi lived in egalitarian bands of twenty-five to forty, with leaders who were first

among equals. Social cohesion was generated by meat sharing (Marshall 1976; Lee 1993), storytelling (Biesele 1993), and trance healing ceremonies (Katz 1982).

Three institutions of Ju/'hoan social organization structured continuity in land utilization and access to alternate residences. First, the Ju/'hoan system of land tenure gave, and still gives, each person the right to inherit a territory or *n!ore* from both mother and father (Lee 1979; Wiessner 1977, 2002a). Achieving a strong hold on a single *n!ore* is based on inheritance and occupying the *n!ore* together with a core of kin who had attained “generationally continuous rights of tenure in their ancestral land” (Wilmsen 1989a, 1989b). Moreover, the Ju/'hoansi say that is desirable to arrange marriages with descendants of those who have married out in previous generations, because land rights of spouses who marry in can then be evoked through their grandparents. In short, Ju/'hoansi manipulate kinship, marriage, and exchange to reproduce land holding groups (Wilmsen 1989b); Ju/'hoan men and women who inherit rights to an area and reside in it permanently become the respected *n!ore kxaosi*, “owners of the place.”

Second, in the distant past, Ju/'hoansi had territory-based named groups, *!ku'si*—for example, giraffes, duikers, ant bears, edible gums, and so forth (Lee 1979). By the time systematic information was collected on the Ju/'hoansi, how these groups operated had been forgotten (Lee 1979). It is not known if membership in named groups was inherited unilaterally or bilaterally, or if named groups functioned as clans. People only know that they were exogamous units. Wiessner could not find any stylistic boundaries that marked named groups; Biesele (personal communication, March 2006) found vague linguistic suggestions that there might have been some feuding between named groups. Clearly, Ju/'hoan organization was more complex in the past (see Passarge 1997).

Third, despite concern with land tenure, boundaries between *n!ores* were not closed (Lee

1976, 1979; Marshall 1976). Far-reaching networks of kinship and *xaro* exchange allowed Ju/'hoansi to gain access to alternate residences when food, water, or social relations in their areas failed. In the 1970s, the average Ju/'hoan had sixteen partnerships, largely with consanguineous kin that were well distributed over people of both sexes, all ages, many abilities, and residing five to two hundred kilometers away (Wiessner 1977, 1982, 1986). These partnerships secured the Ju/'hoansi against the great variation in food and water over time and space in the Kalahari. For example, in the late 1960s and early 1970s, Ju/'hoansi spent an average of three months a year residing in *n!oresi* other than their own, living with *xaro* partners, and utilizing their resources. The average length of a visit was 2.2 months.

Productive *xaro* partnerships were inherited over generations. Some elders passed *xaro* partnerships to their children as they aged, or, upon their deaths, their children took some of the deceased's possessions and gave them to the deceased's *xaro* partners or their descendants, requesting that the relationship be continued. *Xaro* played an important role in marriage in that parents sought spouses for their children who were offspring of their *xaro* partners or close relatives of their *xaro* partners. Conversely, successful marriages initiated new *xaro* partnerships as the immediate kin of both spouses entered into exchange relations with the couple's children.

JU/'HOAN MARRIAGE

All first marriages among the !Kung are arranged by parents, a practice typical for hunter-gatherers of Africa and Australia and other parts of the world (Collier 1988; Murdock 1967.² Discussions of possible marriages sometimes began when an infant was born. Both parents participated, although they did not always agree. Interviews give the sense that mothers often got their way.

Ju/'hoan men were only considered eligible for marriage when they had killed a large animal and undergone the Rite of the First Kill and scarification (Marshall 1976). This could be anywhere from fourteen to thirty-five years of age. For eighteen marriages contracted between 1963 and 1969 in the Dobe area, Howell (2000, 175 and 260) gives a median age at first marriage for women of 17.4 years and for men 25.5 years. From the work of Marshall (1976) and my interviews in the Nyae Nyae area, it appears that men and women were married four to five years earlier before Bantu settled permanently in the area, employed young San men and women, and ridiculed early marriages and polygynous marriages.³ Earlier marriage prior to Bantu settlement is also suggested in Howell's sample of 165 women. Howell, who estimates menarche to occur at 16.6 years, found that 65 percent of women were married before menarche; and for another 30 percent, marriage followed menarche closely. Table 17.1 gives the relation of marriage to puberty for the 39 women in my sample and 102 women from the

TABLE 17.1. *Estimated Time of Marriage in Relation to Menarche for Women Born before 1945*

	WIESSNER	MARSHALL/RITCHIE
4+ years before menarche	7 (18%)	25 (25%)
1–3 years before before menarche	14 (36%)	34 (33%)
Around menarche	11 (28%)	17 (17%)
1–3+ years after menarche	7 (18%)	26 (25%)
Total	39 (100%)	102 (100%)

NOTE: Based on data from interviews conducted by Wiessner in 2005 and preliminary analysis of the Marshall/Ritchie database.

records of John Marshall and Claire Ritchie who were born before 1945. In both studies, more than 50 percent of women were married before puberty and only 25 percent after.

Formerly, when families had children approaching marriageable age, they traveled widely to visit exchange partners and to seek potential spouses for their children. Stories of contracting marriages in the past often involve tales of extensive travels while parents sought spouses. Families of prospective mates exchanged gifts over a period of months to years, and marriage negotiations filled the evenings.

The marriage ceremony itself is simple and has elements of "marriage by capture" (Marshall 1976; Lee 1979; Shostak 1981). The mothers of the bride and groom built a wedding shelter and lit a fire with burning sticks from the fires of both families. The bride was carried to the hut on the back of a close female relative; her feet must not touch the ground else it was believed that she would grow thin. The bride often kicked, screamed, and protested. Peers then "caught" the groom and took him to the wedding shelter, where he sat down by the bride. Both were awkward and showed a good deal of fear, shyness, and respect. Young relatives from both sides joined the couple and talked throughout the evening. It was not unusual for the bride to run away and spend the night in the bush or at her grandmother's fire. She was brought back to the wedding shelter and told that this was her husband, that she must remain with him, and that one day he would be as close to her as her mother and father. In the morning, the couple were washed and rubbed with eland fat and red powder, and the rite was considered complete. After marriage, young men resided with their in-laws and provided them with meat and assistance as bride service until the first two or three children were born. However, this was not a time of one-way flow of goods and assistance but one of frequent visiting and exchange between the two bands; the young man and his in-laws also sent gifts of meat to home to his own relatives. After bride service, the couple was familiar with both sets of kin and could choose to live with the rela-

tives of the husband, the wife, or in a camp composed of relatives of both spouses.

WHAT ARE THE GOALS OF PARENTS IN ARRANGING MARRIAGES?

Parents put enormous effort into arranging marriages for their children at a young age, knowing very well that the marriage might end in divorce within the first year. Why? Ju/'hoansi give three reasons: (1) they want children to marry early so that they would stop relying on their parents for food and become active producers for the camp, (2) they wanted the young people to grow up together and to be educated and become familiar with both sets of kin while they were young and malleable, and (3) because they had located a good potential spouse and feared that he or she would be married to another if they did not act quickly. Table 17.2 gives the reasons for choosing a certain spouse for the sixty-one marriages of people born before 1945 for whom I have good information. The most common response was that the man was a good hunter and could provision the bride's camp with meat. Numerous people said that marriage was "about the meat" (see Marshall 1976 and Bieseke 1993). But not all prospective son-in-laws were good hunters, and men who worked for pastoralists and had access to meat and milk or possessed other skills were also highly desired as sons-in-law.

As or more important than individual attributes of spouses were attributes of the family. A very common response to questions about marriage choices was that a certain spouse was selected because the families were upstanding and had a long relationship of trust, *xaro* exchange, and mutual assistance. Parents felt that if children married into good families at a young age, they would be brought up to be hard-working, generous citizens. Moreover, parents expressed a desire for their children to marry into families with whom marriage had occurred in former generations, bringing the descendants of former marriages back to their original land where they still held weak rights and renewing *xaro* ties between extended families.

TABLE 17.2. *Reasons Given by Parents for Choosing Marriage Partners for Their Children*

REASONS GIVEN FOR CHOOSING A CERTAIN SPOUSE	NUMBER OF TIMES MENTIONED	PERCENT
Good hunter, hard worker who could provide meat for in-laws	39	38%
Families upstanding, close, and had a long-standing relationship of trust, exchange, and mutual help	33	33%
To create ties for <i>xaro</i> exchange	12	12%
Prospective husband worked for pastoralists/hard worker/skills	8	8%
Man was persistent in courting woman/love/stole woman	7	7%
Sisters wanted to be cowives	2	2%
Total	101	100%

NOTE: The first four reasons were given by parents for arranging marriages. The last two reasons represent cases where children's wills prevailed.

To construct new *xaro* ties or strengthen old ones was a goal mentioned in 12 percent of arranged marriages. Long-distance marriages of up to three hundred kilometers were negotiated to create exchange ties that would give access to resources of other areas and to trade goods flowing along the major trade routes of southern Africa (Wiessner 1994). Families that arranged long-distance marriages usually had a history of marriage exchanges and met to negotiate marriages during expeditions to do *xaro*.

Interestingly, the qualities of women were rarely mentioned when reasons were given for contracting specific marriages. It was assumed that the goal of marriage for men was to obtain spouses to gather, cook, and bear children. Women were married at an age when it was uncertain whether they would grow up to be productive gatherers and whether they would grow up to be beautiful. The best proxy for a girl's potential was to come from a good family.

Love figured in 9 percent of marriage choices, when men wanted a particular woman or vice versa and persisted despite the protest of their parents. In two cases, a sister convinced her younger sibling to become a cowife. Love was also mentioned two times in the context of

dismay that a marriage had been arranged with a certain person rather than the desired one.

Physical attractiveness was not mentioned as a concern in choosing a spouse. All twenty-five Ju/'hoansi interviewed insisted that looks did not matter, only the abilities of prospective spouses, the social standing of their families, and relations between families. Indeed, some men who were excellent hunters married women judged as being unattractive but hard workers. Nonetheless, Ju/'hoansi were pleased if their spouses grew up to be beautiful. Extreme ugliness and other qualities, such as being too tall, could be considered negatively, particularly if the person was lazy. Ju/'hoansi did not seek to match characters in spouses, though men with short tempers who were likely to cause trouble were considered undesirable spouses, as were women who gossiped or complained too much (Wiessner 2005).

WHAT DO JU/'HOAN CHILDREN WANT IN FIRST MARRIAGES?

In the past, Ju/'hoansi, like people in many traditional societies, saw marriage as an economic and reproductive institution, though frequently

TABLE 17.3. *Responses of Males and Females to First Marriages*

	WOMEN		MEN	
	N	PERCENT	N	PERCENT
Agreed	10	16%	13	21%
Reluctant	19	31%	27	44%
Strong protest	19	31%	6	10%
Rejected spouse for a long time	9	15%	0	0%
Ego was persistent suitor and won	2	3%	13	21%
Spouses decided themselves	2	4%	2	4%
Total	61	100%	61	100%

NOTE: Pearson's χ^2 test was run with the last category, "Spouses decided themselves," omitted to reduce the number of cells with low expected frequencies. Pearson's $\chi^2 = 13.5$; d.f. = 59; significance level = 0.0001.

very strong bonds developed between spouses over the years (Lee 1993; Marshall 1976; Shostak 1981). Both men and women said that they felt shy about the topic of marriage when they were young and accepted, in principle, that such important unions be arranged by parents. In practice, however, with the exception of a few men who married late, the majority interviewed rejected first marriages. Most girls felt too young to marry, feared marriage and childbirth, and wanted to stay home with their parents and have a longer carefree childhood. Young men were faced the prospect of trying to please a recalcitrant bride and her parents, while waiting for her to go through menarche and become sexually active. They would have preferred to seek their own spouses when they were older among more mature women. Fear of not finding a spouse led them to comply with their parents' wishes.

Table 17.3 gives responses of the bride and the groom in sixty-one first marriages. Sixteen percent of women and 21 percent of men agreed with their parents' decisions that they should marry. Only 4 percent of couples decided to marry by themselves. Thirty-one percent of women protested strongly, kicking, screaming, running away, or giving their husbands a very hard time (see Marshall and Meismar 1980). Marriages provoking such violent protest often

ended within weeks or months. Another 15 percent of women remained in the marriage but rejected their husbands for months or years. Of the forty-seven women who protested marriage, only five mentioned physical features or character attributes of their spouses as a reason for rejection. The rest simply did not want to marry at such a young age.

HOW GREAT WAS THE PARENT-OFFSPRING CONFLICT OVER MARRIAGE?

Parent-offspring conflict over marriage was considerable. Young women would risk their lives spending the night in the bush to protest marriage; parents in turn retaliated by beating recalcitrant brides, or in some cases, the mother or grandmother would threaten suicide with a poison arrow should the daughter not comply. The conflict over marriage was not as pronounced for most men except when men wanted to make their own marriage choices or sought polygynous marriages. Six out of sixty-one (10 percent) first marriages for women in the sample were polygynous, with the men having two to four fertile wives (by contrast, see Howell 2000). Parents of young women rejected polygynous marriages because the products of labor of a son-in-law would be divided

TABLE 17.4. *Outcome of First Marriages in Wiessner and Ritchie/Marshall Data*

	WIESSNER 2005	RITCHIE/MARSHALL
Still together		
after 15+ years	38 (62%)	50 (54%)
Divorce in <5 years	16 (26%)	29 (31%)
Divorce after 5+ years	1 (2%)	5 (5%)
Terminated by death		
in first 15 years	6 (10%)	9 (10%)
Total	61 (100%)	93 (100%)

NOTE: The Wiessner data include men and women; and the Marshall sample, women only.

TABLE 17.5. *Major Marriages for Ju/'Hoansi in Terms of Duration and Number of Children Born*

	WIESSNER 2005	RITCHIE/MARSHALL
Marriage 1	37 (60%)	53 (55%)
Marriage 2	15 (24%)	21 (22%)
Marriage 3	6 (10%)	5 (5%)
Marriages 1 and 2, 2 and 3, or 1 and 3	3 (6%)	17 (18%)
Total	61 (100%)	96 (100%)

NOTE: Major marriages are those that are the longest in duration and produce the greatest number of children. The Ritchie/Marshall data contain women only, and the Wiessner sample contains both men and women. Men and women are combined in the latter because differences between men and women were minimal.

between two families. Parents of young men feared that such marriages would create trouble between families. The only men who succeeded in contracting polygamous marriages in my sample were men who were extremely productive but also aggressive and belligerent. Parents initially protested the marriages but eventually complied because of the men's persistence and because they feared the consequences if they continued to turn them down.

WHO WON?

More than half of the time, parents won in their designs for first marriages and the couples stayed together (table 17.4). Approximately 55 percent of main marriages, marriages that were longest in duration and with the greatest number of children born, were first marriages (table 17.5). In a quarter to a third of cases, the children won and the marriage was dissolved

within a matter of days, months, or one to two years, almost always before the first child was conceived (table 17.4). For 90 percent of first marriages that ended in divorce, the young woman left the husband. If first marriages dissolved before a child was born, the parents waited for a year or two and then arranged a second marriage. As the girl was older and used to the idea of marriage, the majority of arranged second marriages succeeded. When second marriages failed, parents usually gave up and left their children to make their own choices.

WHAT ARE THE CONSEQUENCES OF WINNING OR LOSING?

Consequences of the parents winning are three-fold. First they recruited labor into their camps earlier. This was a serious consideration for parents whose abilities were waning with age because single Ju/'hoan adolescents can be notoriously

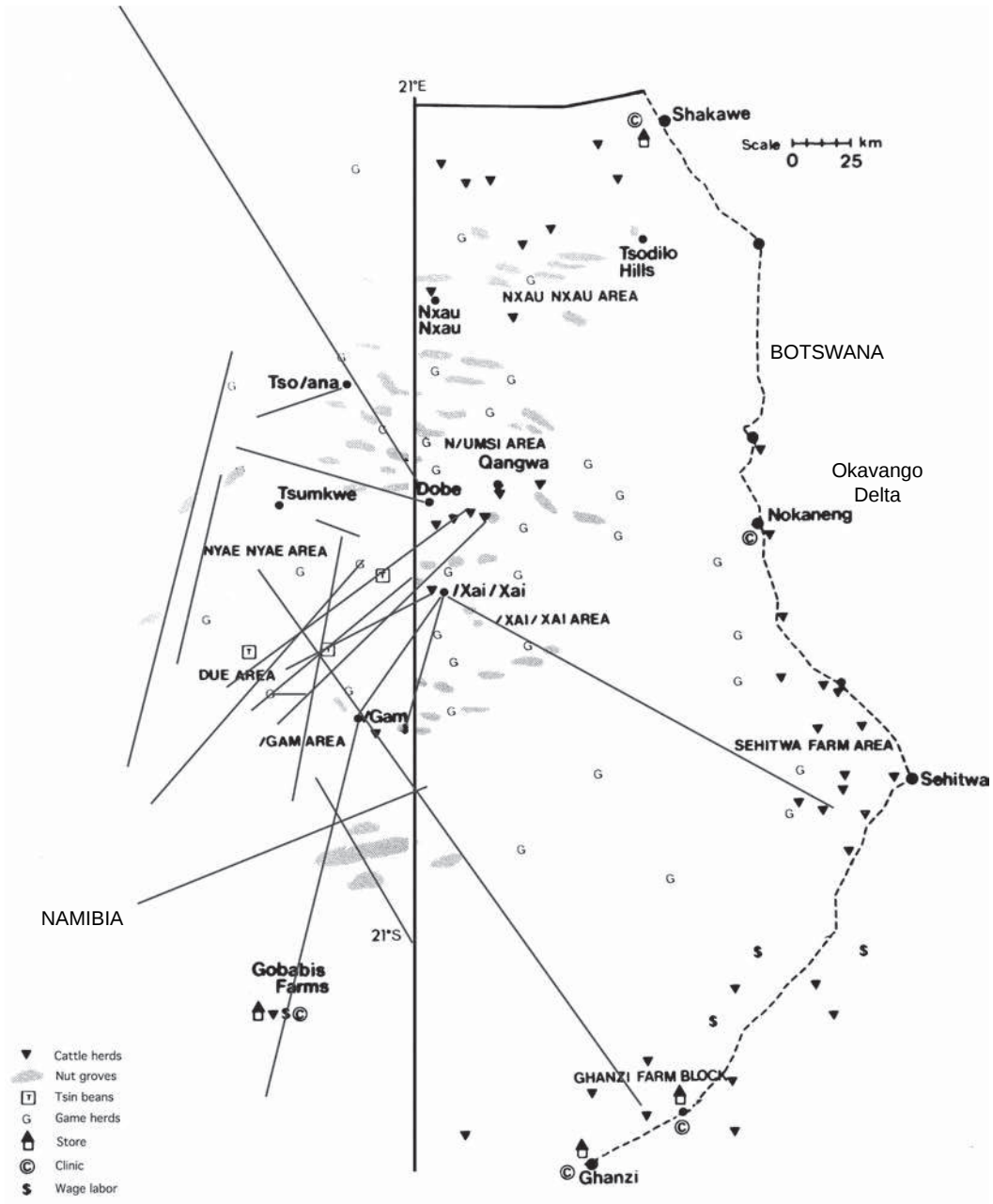


FIGURE 17.1 Map showing marriage distances between spouses who were born between 1886 and 1920. These couples are the parents of the twenty-five Ju/'hoansi interviewed intensively about marriage in the past by Wiessner in 2005.

unproductive and labeled */eri kxaosi*, “owners of the shade.” Marriage and the demands of in-laws prodded young men—and to a lesser extent, young women—into a life of hard work. If young men did not provide meat or work, they risked losing their spouses. Second, in arranging marriages, parents forged long-distance ties that

allowed them to tap into the resources of other areas as alternate residences and to have access to the major trade routes of southern Africa. As can be seen in the map (figure 17.1), networks created or renewed through marriage were indeed vast. Third, marriage brought the descendants of kin who married out in former generations back to

TABLE 17.6. *Comparison of Distance between Spouses in First Marriages Arranged by Parents and Second Marriages Arranged by Parents*

DISTANCE BETWEEN SPOUSES' FAMILIES	FIRST MARRIAGES	SECOND MARRIAGES
<30 km	16 (26%)	6 (37%)
30–59 km	21 (35%)	4 (25%)
60–89 km	14 (23%)	4 (25%)
90–300 km	10 (16%)	2 (13%)
Total	61 (100%)	16 (100%)

NOTE: Pearson's $\chi^2 = 6.827$, d.f. = 16; significance level = 0.6557.

the land of their forefathers, strengthening land claims of the residential group.

When marriages were dissolved within a year, parents lost the effort invested in the arrangements and a few years of additional labor from the young couple. However, there is little indication that second marriages arranged by parents were not as carefully engineered as were first marriages. The figures in table 17.6 comparing distances between spouses in first and second arranged marriages indicate that there are no statistically significant differences. Second marriages, like first marriages, constructed far-flung ties.

WHAT HAPPENED WHEN CHILDREN WON?

When children won, there were two outcomes. First, they gained some years to grow up at home as “owners of the shade.” When older, they may have had more say in marriage preferences, or at least their parents believed them when they strongly rejected a certain prospective spouse. Men who won over parents and succeeded in contracting polygynous marriages in the sample discussed here produced two to three times the children of the average monogamous family. Men gave as the motivation for polygyny, the desire to build an entire camp from their spouses and children.

MARRIAGE SINCE THE 1970S

Those were the outcomes of the everyday struggles over marriages in the past. However, in the last four decades, the picture has changed

entirely after the South African government encouraged people to settle permanently at Tsumkwe in the 1960s and 1970s. At Tsumkwe men were employed in wage labor and later in the South African Defense Force, and both boys and girls attended school. Young men who were employed became financially independent, often did not reside with their in-laws, and did not regularly provide public goods for the camp, though they did share some of their salaries with kin. They were in a better position to make their own marriage choices. Moreover, boys and girls attended the Tsumkwe school and were influenced by Western ideas on marriage choices and were attracted by fellow students. For the thirty marriages of children of Ju/'hoansi in my sample that occurred in the 1960s and 1970s and were discussed in some detail by parents, one was arranged in the traditional manner, six were arranged by both parents and children, and twenty-two decided by their children. In the latter cases, the parents usually disapproved because they felt the couple was too young to make such important decisions, or because the young man was incapable of supporting a family, had bad qualities, or came from a family with whom they had no ties. And so parent-offspring conflict continues into new contexts.

In the 1980s and 1990s, Ju/'hoansi began to settle back on their traditional lands and practice a mixed-subsistence strategy (Richie 1987), relying heavily on government relief food and old age pensions for a large portion of their subsistence income (Wiessner 2004). Even though wage labor opportunities greatly decreased after

TABLE 17.7. *Comparison of Number of Exchange (Xaro) Partners and Spheres of Exchange for Ju/'Hoansi in the 1970s and 1990s*

AVERAGE NUMBER OF <i>xaro</i> PARTNERS LIVING . . .					
	. . . IN OWN CAMP	. . . 1–25 KM AWAY	. . . 26–75 KM AWAY	. . . 76 KM + AWAY	TOTAL
1975	2.6	3.5	7.0	1.5	14.6
1997	2.9	1.8	2.1	0.1	6.9

NOTE: $n = 59$ for 1975; $n = 58$ for 1997.

independence in 1990 and few young men or women can support their families, modern marriages are almost exclusively decided by young people, sometimes with parental approval, but often not. Because villages are permanent and larger, it is not unusual for young people to choose spouses from the same village.

The effects of children rather than parents controlling marriage choices are many. First, men choose more mature sexually active women as brides. As a result, young women stay at home longer, producing little because plant foods for gathering are rapidly exhausted around permanent villages or destroyed by the many elephants in the area today. Second, young men marry whether or not they can support a family; most are not learning to hunt by traditional means, and modern means of hunting are illegal (Wiessner 2004). This puts a burden on parents, and grandparents who receive old age pensions, to help support young families. Third, many marriages today are between young people of families who do not have a history of friendship and exchange and who disapprove of the marriage. When marital strife breaks out, parents who were against the marriage in the first place may be glad to have the spouse go home. When fueled by alcohol, marital disputes that escalate into spousal murders are not infrequent. Fourth, young people, unlike parents, do not consider creating long-distance ties for *xaro* when choosing spouses but choose women they get to know in their own village or in neighboring ones. The erosion of the infrastructure of marriage ties on which *xaro* exchange depended is one factor contributing to

the decline of *xaro* in the past three decades. As can be seen in table 17.7, *xaro* partnerships decreased radically between the 1970s and 1990s (Wiessner 2002b). By 2005, the word *xaro* had virtually dropped out of conversation, and few Ju/'hoansi knew about the *xaro* system of the past. As one old man put it: “Today with the decline of *xaro*, when there is no food in our *n!ores*, we have little choice but to stay put and lie out the hunger.”

WHAT IS THE IMPACT OF MARRIAGE DECISIONS ON MATERIAL CULTURE?

When parents arranged marriages, there was concern with establishing the social standing of families to attract prospective spouses. Families with girls or boys approaching marriageable age doubled their spheres of *xaro* exchange (Wiessner 1982, 1986) and became much more active in the circulation of goods obtained from the major trade routes of southern Africa via *xaro* exchange. Prestige goods—such as impressively wide headbands of ostrich eggshell beads, beaded belts, strings of glass beads, or lavishly beaded aprons—were sought and flaunted by mothers and grandmothers. Subsequently, they were given to prospective in-laws to strengthen bonds. The desire for prestige goods around the time of arranging marriage provided a considerable impetus for long-distance *xaro* exchange and trade. In turn, marriage ties made trade and exchange possible. Thus, with arranged marriages, one sees the emergence of prestige goods in what is otherwise an extremely egalitarian society.

When young Ju/'hoansi choose their own spouses, parents with marriageable children no longer display "prestige" goods. Such goods are readily sold to tourists for cash spent needed to purchase food, blankets, and other essentials to support their growing number of dependents. Today it is young people rather than parents and grandparents who show off to attract spouses with clothing, perfume, creams, and cosmetics.⁴ The association of arranged marriages, systems of land tenure, and more formal social organization is not unique to the Ju/'hoansi. Many Australian foragers who have arranged marriages devote effort to land matters, social networks, formal social groupings, and the trade of prestige goods (Dousset 2005); Hamilton 1982; Keen 2004; Myers 1986; Tonkinson 1991; Tindale 1972). In contrast, the Hadza foragers of Tanzania (Woodburn 1968) and the Ache of Paraguay (Hill and Hurtado 1996), who do not have arranged marriages, also do not have structured social groups, complex systems of long-distance exchange, concern with land tenure, or the acquisition of prestige goods used in marriage negotiations

IMPLICATIONS FOR SOCIAL REVOLUTION

In summary, marriage constitutes an important arena for parent-offspring conflict. Underlying conflicts of interest around who controls marriage have important implications for social evolution. First, one might ask at what point in human history did parents began to take control of the unions of their offspring and use these as a means to realize complex agendas in the interests of groups composed of their offspring and those of close collaterals? Certainly, this would have been a turning point for the development of more formal expressions of human social organization such as clans, section systems, long-distance trade alliances, and systems of land tenure. Moreover, institutions such as male and female initiations, bride wealth, and bride service may have emerged to give parents control over the timing and choices of spouses for their children.

Second, parent-offspring conflict over marriage timing and choices produces tensions in

most societies. Accordingly, change that gives more opportunities to either the young or old is likely to alter the balance of power in marriage decisions and bring about substantial changes in social, economic, and political institutions, as it has among the Ju/'hoansi. Possible outcomes are many: parents may gain exclusive control over marriage; marriage choices may be jointly decided by parents and their sons, parents and daughters, or exclusively by the children with approval or disapproval of the parents.

Finally, signaling carried out in the interest of attracting a mate when children choose their spouses centers on personal qualities: beauty, prowess, and potential to invest in offspring. When parents arrange marriages, emphasis shifts to displaying family or group reputation, fueling the emergence of prestige goods and wealth displays. Who wins in parent-offspring conflict over marriage, how decisions are institutionalized, or what formal compromises are reached will have strong implications for social evolution and material culture.

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NOTES

1. I began this research in 2005, so results presented here are preliminary; much research remains to be done. Further analysis of the Ritchie/Marshall database is in progress. In 2006, I began research on current marriage choices.

2. Arranged marriages are frequent in Africa; to give some examples: !Xo (Heinz 1994), G/wi (Silberbauer 1981), Okiek (Kratz 1988), and Mbuti (Turnbull 1965) parents arranged marriages for their children. In Australia, marriages are arranged by parents widely throughout the Western Desert (Hamilton 1982), among the Mardu (Tonkinson 1991), Pitjandjara (Tindale 1972), Pintupi (Myers 1988), Walbiri (Meggitt 1962), and Tiwi (Goodale 1971).
3. Lee's (1979) survey of 151 Ju/'hoansi men in 1968–1969 indicated that 83 percent of Ju/'hoan men residing in Botswana had lived or worked with Bantu.
4. Young people whom I employ spend a good portion of their salaries at the Tsumkwe stores on items to beautify, even when they themselves, their parents, and their siblings are severely short of food.

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EIGHTEEN

Prestige Goods and the Formation of Political Hierarchy

A COSTLY SIGNALING MODEL

Aimée M. Plourde

PRESTIGE GOODS, STATUS STRIVING, AND THE DEVELOPMENT OF SOCIAL RANKING

Graham Clark (1986, 82) observes that the particular “hierarchies of esteem” of materials considered to be precious vary—sometimes widely—by culture, “yet the transmission of precious substances in the form of jewelry or other objects of display has at all times and most notably during the last five millennia served the same purpose the world over, that of signalling and enhancing status,” an observation commonly thought to apply more generally to prestige goods of all kinds. For this reason, scholars studying the development of social institutions and structures of ranking and political hierarchy, particularly archaeologists, typically interpret artifacts postulated to be prestige goods as indicators of the presence of status ranking in past societies.

The advent of formalized and permanent social status ranking, including leadership positions and political hierarchy, constitutes one of the most fundamental transformations of

human society, one that took place very late in human history and very rapidly in comparison to the time scale at which physical transitions in human evolution took place. One of the major difficulties in understanding this transition is explaining why people voluntarily participated in its creation, given that in doing so most would have been accepting limits to their autonomy. Ethnographic accounts of contemporary egalitarian societies suggest that people are averse to such limits and demonstrate that strong norms against status striving often exist (Boehm 1993, 1999; Kelly 1995, 296–297; Lee 1979).

Recent archaeological theory proposes that ambitious men, coined “aggrandizers” by John Clark and Michael Blake (1994), were in large part responsible for the beginnings of social hierarchy. These individuals are empirically observed in ethnographic and historical accounts of many tribal and chiefly societies, and they are typically characterized as desiring prestige and as using prestige goods to gain prestige and attract followers. But why do these individuals want prestige and seem more willing than

others to expend effort to achieve it, and how exactly do prestige goods confer prestige on their owners? Examining these issues provides a point from which to more critically examine the “nature” of aggrandizers, and from there to construct more detailed models of their role in the processes of increasing social rank.

PRESTIGE GOODS' ROLE IN THE CONSTRUCTION OF SOCIAL STATUS

Johnson and Earle (2000) characterize how prestige goods work in slightly and moderately ranked societies:

Valuables are critically important in establishing a person's social position . . . and in gaining personal prestige and associated political office. Valuables are marks of social status that define an individual's political and economic rights in a society. By channeling the distribution of the valuables, ranking chiefs used them almost as a political currency.

Observations like this one have led to the general conclusion that prestige goods must have played some role in the initial appearance of social ranking and political hierarchy, specifically through convincing people to give up some of their autonomy and accept the authority and direction of would-be elites. This role may have been a particularly key one, given that little evidence exists suggesting that early high-status individuals and groups used force or violence to achieve or keep their elevated positions.

It is generally assumed that prestige goods are able to play such an important role in the development of social ranking because of the value placed on such items—the esteem in which people hold such goods and their motivation to possess and display them. If prestige goods played an active role in the emergence of social status ranking and formalized leadership, rather than merely reflecting differences in social power and resources, then it would be circular reasoning to argue that the source of their value was as indicators of status differences and wealth. Apart from their association with elevated status, the value of prestige goods is attributed to their scarcity or the labor involved in their manufac-

ture: prestige items may be exotic, finely crafted, or have special properties, but are almost always difficult to obtain in some way. However, they rarely have a utilitarian function or are valued much more highly than expected given their use function. Helms (1979, 1993, 1994) attributes the value of these exotic or finely crafted items to their embodiment of intangible powers and energies from the cosmological realms of gods and ancestors; she further asserts that not only objects from distant locations but knowledge of those locations can be a source of power (Helms 1988). While her arguments are compelling, they beg the question of why humans should universally have a feeling of reverence for geographically distant locales and how it might influence the use of valuables.

To resolve this problem, a theory is needed to explain the emergence of prestige goods apart from, and in all likelihood predating, the existence of social ranking and political hierarchy and of the attendant socioeconomic differences these generate. It must be explained why the possession and display of such goods increases the prestige of their owner, and why having prestige leads to increased authority and social power.

A THEORY FOR THE ORIGIN OF PRESTIGE GOODS

Any explanation of prestige goods' role in augmenting prestige must articulate with what is known about the psychology and behavior of prestige, a phenomenon unique to human beings. In all other social species, including non-human primates, social ranking appears to be determined by dominance alone (Ellis 1995; Henrich and Gil-White 2001). In humans, dominance, which also includes coercive abilities due to socioeconomic resources, is certainly present in social relationships; and given its pervasive presence in our closest primate relatives and the social interaction of animals generally, it is reasonable to assume that dominance existed during the entire course of the hominid evolutionary trajectory. Nevertheless, prestige is at

least as pervasive as dominance in contemporary human social groups and likely just as important in shaping social relationships (Barkow 1975, 554). It is a “human universal” (Brown 1991), existing in all groups of people regardless of overarching political structure and degree of social ranking present.

Prestige is defined in common usage as respect and deference freely conferred on an individual by others, not compelled through violence, threat, or coercion. A person having prestige is honored by peers and wields influence over them. Social scientists who focus on the formation of political structures emphasize that prestige is associated with having authority and thus a form of social power. Demonstration of excellence in some valued domain of activity is one of the main ways by which a prestigious person achieves the respect of others and thus influence over them (Henrich and Gil-White 2001, 167). An interesting repercussion of this fact is that many different hierarchies of prestige can exist simultaneously (Henrich and Gil-White 2001, 170). While the diversity of economic and leisure activities in contemporary Western society allows people to achieve great renown from having skill in one or several of a wide range of activities, the range of possible activities likely would be more limited in traditional societies.

THE ORIGINS OF PRESTIGE PSYCHOLOGIES AND BEHAVIORS

If prestige processes arose early in modern humans’ evolutionary trajectory and have remained a pervasive feature of human psychology and social interaction, then it is likely that prestige is a product of design by natural selection. What adaptive function does prestige serve? And what in the evolutionary past of humans led to strong selection for prestige that was not present in all other species, including those most closely related to us? Recent work in evolutionary psychology has begun to address these issues, focusing on the function of prestige in small-scale societies of the kind hypothesized to have characterized human groups in the evolutionary past.

Henrich and Gil-White (2001) have recently proposed a model for the origins of prestige in early human societies. They suggest that, as culturally transmitted knowledge became increasingly complex and important for success, selection could have favored new strategies to assist in social learning. Juvenile, learning individuals, or those who simply wish to improve their success, such as recent migrants to the group, would benefit from learning from successful individuals, through observation and imitation as well as through direct teaching. Henrich and Gil-White theorize that selection would have favored the development of psychological mechanisms to assist in determining which members of a group are successful, and to generate admiration and attraction to that individual as motivation to maintain proximity to her and to copy her behavior. Furthermore, these feelings of attraction and admiration would also cause the learning individual to treat the target with increased respect and deference, as a means of providing the skilled individual with a reason to tolerate the proximity of the learning individual and to interact with her. It is also likely that prestigious individuals received other kinds of positive benefits in social relationships, such as leniency after a transgression of group norms or a failure to reciprocate in dyadic relationships, and possibly more support for self and family members following injury (see Bateson 1958, 91; Hawkes 1991, cited in Henrich and Gil-White 2001, 182–183). Because average skills can be attained from one’s parents and close relatives without deference payments (Henrich and Gil-White 2001, 179), clients should only be willing to pay for above-average levels of skill and knowledge. However, to the degree that the transmission of skills and knowledge is strictly vertical (from parents or other close relatives) (Shennan and Steele 1999; also see Tehrani and Collard, this volume), the opportunity to acquire prestige benefits from learning individuals should be limited.

Henrich and Gil-White’s model presents a compelling argument for how prestige could have arisen as the result of learning individuals’ desire to copy successful individuals. This model

explains three important observed facts about the psychology of prestige: (1) why people admire and defer to successful, skilled individuals, (2) why people desire to be prestigious, and (3) why people pay attention to those to whom others give prestige.

COMPETITION FOR PRESTIGE

Obviously, the possession of good skills and knowledge should improve an individual's personal fitness. If having prestige from the possession of those skills and knowledge further confers benefits on an individual, and if it also outweighs the costs associated with the presence of a group of inquisitive admirers and possibly time spent teaching, then skilled individuals should be motivated to strive for prestige. Henrich and Gil-White briefly address the issue of competition for prestige, suggesting that because prestige is freely conferred by clients on their "patrons" and clients are at liberty to "take their business" to whomever they chose, the distribution of prestige clients to patrons will have aspects of a market (Henrich and Gil-White 2001, 171, 178–179). If highly skilled models increase their benefits from prestige with every admiring client they gain, up to some optimal number, then models should do what they can to encourage clients to choose them as their patron. Henrich and Gil-White suggest that when competition for clients is high, then models should modify their behavior—be less arrogant, more approachable, and so on—in order to attract and retain clients (Henrich and Gil-White 2001, 171, 178–179).

Increasing affability is only one way that a would-be model could convince prospective clients that he is a better choice than one of his rivals for prestige. I suggest that an alternative strategy would be for a skilled individual to behave in some way that would convince prospective clients that his skills are better than those of other potential models. One way would be to signal his success with physical items. Since people should be predisposed to pay attention to the prestige rankings of the other members of their group, I would argue that this predisposi-

tion could expand to include other kinds of information that helps clarify prestige ranking, such as material possessions.

PRESTIGE GOODS AS COSTLY SIGNALS OF SKILL AND EXPERTISE

Drawing on costly signaling theory, I suggest that material items that honestly reflect some aspect of an individual's skills or knowledge could act as an advertisement in prestige competition and, as such, would constitute "prestige goods." The ways in which physical items could reveal success are numerous, in theory varying as widely as the number of skills and knowledge that a person could possess. Prestige goods could demonstrate skills directly related to making a living, such as hunting, craft production, or knowledge about the environment. They could also reflect the quality of an individual's social contacts outside the group, as might be important during times of environmental stress or other crises. Finally, prestige goods could signal success at a more general level in the amount of extra time or labor that an individual has to acquire and/or produce the item. The link between the signal's content (the skill or knowledge that the potential prestige client wishes to gain), and the specific form that it takes distinguishes prestige goods as a signal from other kinds of signals that could possibly and probably did exist, those aimed at different audiences, including potential mating partners, potential rivals for mating partners, and competitors for other kinds of resources.¹

The idea that material goods can serve as signals of personal quality and social standing is an old one, dating back at least to Thorsten Veblen's (1899/1994) *Theory of the Leisure Class*; his idea of "conspicuous consumption" describes how people use the display and consumption of costly luxuries as a believable way to advertise the amount of wealth they possess. The cost of the signal, in this case in terms of wealth, is the assurance of its honesty. A substantial literature on signaling theory now exists (for a complete treatment, see Maynard Smith and Harper 2003), developed in economics in

the 1960s and independently in evolutionary biology somewhat later, following Zahavi's "handicap principle" for fitness indicators under sexual selection (Zahavi 1975, 1995; Zahavi and Zahavi 1997). The dynamics of this idea have been formally modeled by Grafen (1990), Maynard Smith (1991), and others.

While signaling theory is not limited to scenarios of sexual selection, recent applications of it to human behavior from evolutionary psychology and human behavioral ecology have remained mostly within this area (see, e.g., Miller 2000). Pertinent to the present discussion, several scholars have proposed that contributions to public goods may be costly signals made in an attempt to gain prestige and related personal benefits, including the hunting of large game animals for public consumption (Bird et al. 2002; Smith, Bird, and Bird 2003) and the punishment of transgressors for violations of group norms (Gintis, Smith, and Bowles 2001). Recently, archaeologists (Boone 2000; Neiman 1997) have also begun to explicitly draw on costly signaling theory to explain status striving following the development of some degree of leadership and social ranking.

INCREASING COMPETITION AND THE EMERGENCE OF PRESTIGE GOODS

We do not know the time frame for the emergence of the psychological mechanisms underlying prestige-based exchange of knowledge for deference, but it likely was part of the transition to fully modern *Homo sapiens*, given that prestige is a part of all human societies. Prestige goods, in contrast, do not appear in the archaeological record until later, at different times in different regions of the world. The variation in the timing of the appearance of prestige goods implies that levels of competition for prestige have varied substantially across groups. What could cause prestige competition to escalate, such that the use of novel competitive strategies, including prestige goods, could be favored? I suggest two factors: (1) increasing group size and (2) increasing complexity and/or number of skills and realms of knowledge necessary for success.

An increase in the number of group members could favor the use of prestige goods in two ways. First, all other things being equal, as group size increases, the number of people in the group with some degree of success should also increase, although the number of the most highly skilled individuals (the best models) should be smaller relative to the group as a whole. As the number of successful people in a group rises, learning individuals would have more choices from which to select a model. Therefore, the level of competition between successful individuals to attract admiring followers should increase. Second, as the number of skilled individuals rises, it should also become more difficult for learning individuals to determine which individual is the most successful and therefore the best choice of model. In this context, a skilled individual who chooses to advertise her degree of skills/knowledge may have an advantage.

The expansion in skill and knowledge sets available and important to success could also favor a strategy of advertising. As new skills are added to the repertoire of ways of making a living and existing skills and bodies of knowledge are expanded and become more complex, the difficulty of learning everything necessary for success should increase. This in turn should make it more important for learning individuals to have access to a good model and should make learning individuals willing to invest more energy in evaluating potential models, and to increase the amount of social benefits they are willing to bestow on successful individuals in exchange for proximity and teaching. An increase in the benefits received from having prestige could compensate for increased costs incurred to win prestige competition.

In summary, building on Henrich and Gil-White's theory for the adaptive function of prestige, I have proposed a model to explain why prestige goods should function to augment a person's prestige and under what conditions they should first appear. I theorize that increasing competition for prestige "clientele" and the increased benefits to be gained from them could

favor new strategies to win prestige competition, including the use of physical goods as advertisements of degree of skill and knowledge. The factors influencing these two conditions—including the size of social groups, rates of innovation, and the size of cultural bodies of knowledge—are numerous and complex, and it would be beyond the scope of the present work to attempt to discuss them in detail. It is worth noting, however, that they include increases in population size, increasing group circumscription and technological innovation, which are also often implicated in the emergence of social inequality. Thus, while this model for the origins of prestige goods contains no causal arrow between the emergence of prestige goods and social ranking, it could well be the case that the stimuli for both lay in these overarching forces.

PRESTIGE GOODS AND THE SELECTION OF LEADERS

How then could prestige goods, as honest signals of an individual's skills and expertise, play a role in the formalization of leadership and the development of social ranking? Drawing on ethnographic observation of how leaders are chosen in contemporary egalitarian² societies, I suggest that prestige would have played an important part in who is selected—or accepted—as leader. Leaders for a given activity are usually selected from among those who have experience and/or skill relevant to the task at hand; in other words, they should have prestige in that particular arena. In groups experiencing increasing competition for prestige due to the factors cited, prestige goods should be one of the ways that a potential leader's skill and knowledge could be evaluated by the group.

While in egalitarian societies the authority that such a leader has is generally restricted to that specific activity and so is ephemeral, in groups experiencing increasing selection for the ability to act collectively, leadership would be needed more frequently and be more important to group survival, providing the opportunity for leadership to become more permanent.

Many ethnographic and historic examples support the idea that groups with the ability to organize themselves in efforts for the common good, such as military action and cooperative tasks for production, often do better than their neighboring groups. For instance, if intergroup conflict over resources or land increases in frequency and intensity, groups with an individual recognized to lead and organize group defense and raiding might be more successful than groups without such a leader. The same logic could apply to leading and organizing group labor for public goods projects, such as the construction and maintenance of irrigation systems, fish weirs, and the like.

Archaeologists generally agree that increasing population density, increasing group circumscription and conflict, and the intensification of subsistence production are factors that encourage the appearance of social stratification, while there is disagreement as to which, if any, are primary motors. If efficient collective action becomes more relevant to a group's success, then the presence of a leader to coordinate such activity may be one of several possible social institutions that are favored and become more common. In this way, competition for personal prestige, and thus prestige goods, could become linked to competition for the social power held by someone occupying a leadership role.

In this novel context of competition, prestige goods could fill a similar function to that described previously, but in this case acting as honest signals of skills and knowledge pertinent to leadership of collective action. For instance, material items could honestly signal a would-be leader's skill in group defense and/or raiding. In the Shuar, an egalitarian group living in the Amazonian lowlands of Ecuador, historical accounts relate how warriors retained the heads of those they killed during conflict with other groups, which then served as honest signals of a warrior's ferocity and success in conflict to his own group members. It is important to note that these items were displayed only in ceremonies for the warriors' own group and were not displayed to members of other groups;

in other words, they were not being used to intimidate their enemies.

Exotic (nonlocal) goods could index the quality of a would-be leader's external contacts, which in this new context of group competition would be important for trade and political alliance. The Kula Ring, a complex system of exchange among the Trobriand Islanders of the western Pacific, is one of the most famous examples of the importance of a prestige good system to the means by which leaders affirmed but also manipulated their elevated social rank. A chief's status was based not only on his inherited rank but also on his successful participation in the Kula and competitive yam harvests. Exchange of prestige goods between elites created networks of alliance and obligation between them, and display of the items at home after trading voyages acted as a measure of a chief's success, demonstrating his political prowess and economic capability and thus augmenting his prestige and cementing his authority.

I suggest that it was through this process that prestige became linked with social roles of leadership and elevated status. According to this model, prestige goods played an important part in the initial appearance of social ranking and more formalized leadership positions by providing one of the means by which leaders were selected or approved by group members for their abilities. The reason that they were able to play this role is fundamentally grounded in their operation in groups without ranking, where they arose as a result of individual learning strategies.

This alone would be only a partial explanation of the role that prestige goods continued to play in the formation of social ranking and political hierarchy; obviously later in time, prestige goods no longer function only, or even mostly, to signal individual skill and knowledge. Nevertheless, it is a critical point that that they could have begun their functioning in just this fashion because of its connection to the motivations and attitudes shaping people's behavior with regard to prestige goods. However, once leadership roles and the cultural norms and social institutions supporting them were in existence, their presence and

actions had dramatic and far-reaching impacts on both the operation of prestige goods and on the nature of social ranking.

PRESTIGE GOODS AS COSTLY SIGNALS OF SOCIAL POWER AND GROUP STRENGTH

It is very likely that occupying a position of authority brings with it personal benefits and opportunities to augment one's own as well as one's family's well-being, apart from the benefits to the group of having a leader, shared among all members. For example, Johnson and Earle (2000, 126) observe that headmen and Big Men are often polygynous and thus likely have elevated reproductive success. I follow these and other scholars in hypothesizing that the pursuit of personal advantage for themselves and their families could have contributed to the development of increasingly distinct levels of wealth and social power between different individuals within a group, and over time between their families and lineages.

I theorize that the association of leaders' abilities with prestige items and the involvement of leaders themselves with increasing disparities between kin and coalitional groups within a community forged a link between prestige goods and this novel dimension to social relations, "elite" social status. The possession of elevated social status through membership in a successful kin group would have enormous impact on an individual's social relations, making it beneficial to advertise it to others with whom she might interact. The audience for such a signal would differ from that for signals of skill: the latter would be those learning individuals looking for a skilled model, while the former would be widened to include all group members with whom the signaler might interact. Social status is now comprised of more than personally derived prestige and dominance; it now includes access and rights to resources, access to persons in position of authority, and so forth. In effect, the aspect of political and economic coercion has been added to the interpersonal dynamics in a group. Prestige goods

operating in this new social context continue to function as a signal, rather than a cue or an index, of social status. Just as the number of kills a hunter makes to eat is an index of his skill rather than a signal to learning hunters, the amount of social status an individual possessed should be indexed by things and actions directly related to furthering her survival and success: health, number of children, and the like. Prestige goods, in contrast, can reveal the political and economic power she can bring to bear that might otherwise not be observable.

The second way in which the existence of leaders transformed the signal content of prestige goods derives from leaders' ability to access and direct the labor of others. The amount of labor possessed by a group and the social power embodied in a leader's ability to direct that labor is in itself a new kind of quality that describes both a leader and his group. I argue that the signal content of prestige goods was expanded to include this aspect of social power. This new signal would be used by would-be leaders within a group and between the groups that these leaders represent. In a world where groups are increasingly interacting with one another as units (where factions form within a single group, and groups form larger factions of alliance), the quality of group strength and the ability to advertise it would take on a pertinence not previously possessed.

This general idea is by no means a new one; archaeologists have often employed the general idea that prestige goods act as signals of group and leader strength in models of the development of factional and peer polity competition. Several scholars have recently drawn on evolutionary frameworks and methods to examine the costs and benefits of prestige goods and other signals of competitive strength in terms of energy and, ultimately, reproductive and cultural fitness. Neiman (1997) created a model to support the common supposition that conspicuous consumption is universally a symbol of power. Specifically, in the case of the Maya, he proposed that carved stone monuments function as costly signals of what he terms political "competitive

ability," which he defines as the ability to win political contests with competitors (270). Level of ability depends on a variety of variables, among them "physical size, physiological condition, fighting skill, and psychological cleverness, which contribute in varying proportions to an individual's ability to build and maintain coalitions comprised of kin and non-kin." By winning political contests, individuals affect their individual reproductive success by gaining or losing access to mates and resources. In this way, Neiman links social power as a currency to the currency used in all other evolutionary analyses of animal behavior. This model is one of selection at the level of the individual, but it may also draw on kin selection to the extent that the performance of leaders in political competition relies heavily on the actions of their immediate family and kin networks (Neiman 1997, 271). This logic can be extended to nonkin corporate groups as well, and thus the problem could also be approached from a group selection perspective.

Pletka (2001) adopts an explicitly group selection approach in examining the possible function of Neolithic and Bronze Age Danish earthwork monuments (mounded graves and enclosures) as costly signals of group strength, by which term he specifically refers to the capability to defend rights to land and resources. Earthen monuments, like carved stelae, are just one of many possible ways to signal defensive capability, and I would argue that Pletka's model of honest signaling of group strength via the construction of earthen monuments could be expanded and adapted to apply to all such signals more generally. Like Neiman and Pletka, Boone (2000) uses costly signaling theory to answer the question of why conspicuous displays of wealth expenditure are universally associated with social inequality. His model addresses all material forms of display, including elaborate monumental architecture, exotic and nonfunctional objects, and also elaborate feasts and gift-giving performances (84–85).³

The emergence of these two phenomena—the formation of family and lineage social rank differences and the increasing interaction

between factions via their leaders—transformed the social landscape in which prestige goods were being used in dramatic and fundamental ways. Correspondingly, the content of the signal being made with prestige goods was significantly expanded in these new social contexts, in turn impacting their role in increasing political and social ranking. One result was that self-promotion and aggrandizement using prestige goods, once rebuffed by social equals, could become a tactic used by would-be leaders in advertising their social power and the success of their group, as well as in drawing followers into accepting their authority.

PRESTIGE GOODS AND THE AGGRANDIZER

Hayden's (1998) aggrandizer model of prestige technology posits that aggrandizers constituted one of the major forces of change in human societies, leading to the emergence and elaboration of sociopolitical ranking among other significant changes. According to this model, these changes are the sum result of aggrandizing individuals seeking to promote their personal self-interest through various means, the use of prestige goods being an important one. Hayden posits that "aggrandizing personalities" exist in all human populations but need only constitute a small percentage of a group in order to provoke change in social structure. He defines a person with this personality as ambitious; socially, politically, and economically aggressive; acquisitive; risk taking; as someone who manipulates other individuals in order to promote his or her own self-interest, and who often acts selfishly rather than in the interest of the community, concluding that "aggrandizers have, in effect, an inner motor, an inner drive to increase their own standard of living and their own reproductive success" (18–19).

The model of prestige goods function presented here should contribute to our understanding of the aggrandizing personality. Drawing on evolutionary principles, I would suggest that all people have such an "inner motor" to improve their lives and their reproductive success. In fact,

in animals with longer life spans such as humans, reproductive success hinges greatly on having success in life skills. This idea underlies Henrich and Gil-White's theory for the emergence of prestige as a means for both learning and skilled individuals to simultaneously improve their success through an exchange of benefits. My own theory for the emergence of prestige goods as signals of personal "quality"—in terms of skills and knowledge—also hinges on the idea that such benefits are sufficiently valuable to personal success that they drive competition to obtain prestige goods and to display them.

In any given group, there will be variation in the levels of skill and breadth of knowledge possessed by group members, determined by age and experience as well as talent. Because skill level should change (with any luck improve) over the course of the lifetime, so, too, should behaviors involving paying attention to and obtaining and displaying prestige goods. I propose that the part of the complex of personality variables constituting the aggrandizer composed by the desire to own and display prestige goods as well as to pay attention to them and admire them should exist in all people, rather than being limited to a certain personality "type." Which behavioral strategy a person uses at a given time could be called state-dependent, in that the choice to obtain and display prestige goods should depend on the level of skill and success currently possessed by the individual, and it should change during the course of the individual's life with their degree of competency.

The advent of leadership roles and social ranking would have considerable impact on the expression of these psychological dispositions. For one, the increased benefits from occupying a leadership position and the corresponding increase in competition for prestige that should accompany it could manifest in part as an augmented desire to possess and display such goods. Also, I have argued that the development of social ranking would give all individuals a new kind of quality that they would benefit from signaling to potential mates, allies, and

competitors. It is likely that both the increased importance of signaling personal skills and the addition of new signal content could augment the level of desire to own and display prestige goods already in place.

This augmented desire in turn should have had significant ramifications for the behaviors of would-be leaders, encouraging not just the display of prestige goods but also distribution of such items to followers. The distribution of prestige items by would-be elites should attract followers due to a psychology already in place that encourages owning prestige items as a means of increasing prestige and the associated benefits, and more generally as imitation of the behaviors of successful individuals. I argue that it is by tapping into these deep-seated desires that aggrandizers are able to shape political alliances by display and distribution of prestige items to group members, thus providing one of the mechanisms by which hierarchical power relations within the group develop.

CONCLUSIONS

The model proposed in this chapter addresses the problem of the origins of the value of prestige goods in the absence of formalized and heritable social rank differences, wealth, and other sources of coercive social power. It attempts to explain the role played by prestige goods in the processes leading to the emergence of social institutions underlying them. I began by positing that prestige competition in early egalitarian societies should have existed independent of the opportunity for formalized leadership roles and social ranking differences to emerge. In this context, prestige goods could come into being as costly signals of personal success and skill as a response to increasing levels of prestige competition, resulting from increasing group size and expanding skill sets and knowledge. When selection at the level of the group favors those with the ability to act collectively and thus a social position of a leader who coordinates and directs such collective activity, a new arena for competition is created. Prestige goods now fill

an additional role, acting as costly signals of leadership ability in competition for leadership and social rank in transegalitarian societies. This theory thus links how prestige goods operate in individual strategy to their role in political process, group competition, and ultimately the development of social ranking and political hierarchy. Obviously the model at present is a very simplified one, and it does not examine the role of other factors in the establishment of personal status or the emergence of permanent, formalized social inequality. Closer examination in the future of different processes outlined in the model will hopefully lead to a better understanding of such interactions.

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NOTES

1. In the case of potential mating partners, while they should desire a successful mate and thus presumably one with high levels of skill and knowledge, they should be less interested in the exact nature of those skills, given that they are not interested in learning those skills themselves. The same is true of rivals; they should be most interested in assessing the strength and competitive abilities of their rivals and not be interested in the particular details of their rivals' skills. In all of these cases, while potential mates and rivals should certainly pay attention to such signals once they are in existence, their interest in the success and formidability of the signaler should not be sufficient to cause signals of skill and expertise to appear in the first place. The honesty of the

signal must be maintained by a cost because of the conflict of interest between the signalers and the signal's audience, although the purpose of signaling is to coordinate skilled and learning individuals for their mutual benefit: while signalers would always benefit from receiving deference and other social perquisites from admirers regardless of their level of skill, learning individuals will benefit from the exchange only if the signaler truly is skilled or knowledgeable.

2. By the term *egalitarian*, I specifically refer to an absence of formalized leadership positions or social ranking. It is likely the case that status differences have always existed in human societies—by age, sex, and level of skill—and prestige differences do exist in contemporary egalitarian societies.
3. All of the models just discussed share strong similarities with the literature on contests in theoretical biology. Work here has demonstrated that signals between competitive rivals can evolve when signaling unobservable qualities relevant to fighting, thus transferring information about who is more likely to win a fight and allowing the outcome to be predicted, could prevent both parties from engaging in a costly contest. However, the winner of such contests attains dominance over his rival, not prestige from him. While competition between individuals, and later between groups of increasing size, also characterizes human interaction, I do not believe that this is sufficient to explain how prestige goods initially emerged or how such goods became initially involved in leadership and ranking. Rather, I would argue that once leadership and social ranking existed, prestige goods' use was transformed through involvement in competition between rivals, and it took on an expanded signal content having to do with coercion and dominance through their links with authority and social power.

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NINETEEN

Population and Warfare

A TEST OF THE TURCHIN MODEL IN PUEBLO SOCIETIES

Timothy A. Kohler, Sarah Cole, and Stanca Ciupe

ECOLOGIST PETER Turchin and anthropologist Andrey Korotayev (2006) propose that population size and incidence of internal warfare or sociopolitical instability exhibit a deterministic relationship in prestate societies. Important to their thesis is that both population size and incidence of instability are, and must be treated as, dynamic variables: population growth eventually causes an increase in instability, with a lag, whereas increased instability, also with a lag, eventually leads to decreases in population size.

Because of these lags, they argue that a straightforward attempt to cross-tabulate current incidence of warfare against current population size, as done by Keeley (1996, 117–121, 202), for example, is theoretically indefensible and, practically, likely to lead to spurious results. Indeed, Keeley's tabulation failed to confirm a positive relationship between population size and instability in a series of societies of various scale,¹ although Ember (1982) demonstrated a positive relationship between population density and likelihood of warfare for land in a sample of twenty-six societies, and a positive relationship

between the frequency of warfare and the severity of food shortages in an almost nonoverlapping sample of fifteen societies.

In his 2003 book *Historical Dynamics: Why States Rise and Fall*, Turchin has developed the case for fundamentally similar but somewhat more complicated relationships between population and warfare in agrarian states (see also Turchin 2005). His thesis has not been met with unalloyed enthusiasm. Tainter's (2004) review of the book faulted it for reviving a cyclical theory of history, for simplistic analysis, and for naive social theory. We have seen no discussion of Turchin's model for prestate societies, but the analysis deserves attention because of the extreme importance of the universal relationships claimed.

We have a more modest motivation here as well. One of the cases that Turchin cites as supporting his model is a sequence of tree-ring dates published by Varien (1999) from a portion of the prehispanic Mesa Verde region. In this chapter, we will examine the relationship suggested by Turchin and Korotayev with data from a nearby location in the same region, developed in the context of a current National Science

Foundation (NSF) Biocomplexity project (Kohler et al. 2007; Ortman, Varien, and Lee Gripp 2007; Varien et al. 2007). Because of advantages for which we cannot take most of the credit, this seven-hundred-year time series (from A.D. 600–1300) represents one of the most accurate and precise demographic data sets for any prehistoric society in the world.

THE TURCHIN MODELS FOR POPULATION DYNAMICS AND INTERNAL WARFARE IN NONSTATE SOCIETIES

Turchin proposes two related models for the interaction of the variables population density N and warfare intensity or frequency W . Both assume the same equation for N :

$$\frac{dN}{dt} = rN \left(1 - \frac{N}{K} \right) - cWN \quad (1)$$

Except for the cWN , this is the familiar function for the logistic growth of human population to some carrying capacity K . Turchin defines W here as the annual death rate due to warfare.² The constant c refers to the rate at which the warfare leads to additional death in the population; we added this during fitting, and it is not part of Turchin's published model.

The dynamics of the other state variable, warfare (W), might be understood in two slightly different ways. In the first case, Turchin assumes that W is directly proportional to the encounter rate among individuals of different groups (e.g., in foraging parties). If two groups send out foraging parties at the same rate, then their total number is proportional to N ; a single party will encounter parties from the other group at a rate also proportional to N ; and the total number of encounters will thus be proportional to the product of $N \times N$ or N^2 .

The second assumption of the first variant of this model is that warfare declines gradually at the exponential rate b in the absence of new hostilities. The prominence of revenge as a motive for warfare in nonstate societies in general (e.g., Chagnon 1988), and quite possibly in the

northern U.S. Southwest (Lekson 2002), suggests the utility of this term here. Since b and W are multiplied in the final term bW (which is the rate at which combatants are willing to give up on warfare as a strategy), high values for warfare intensity will lead to more rapid deescalation, presumably as a result of warfare fatigue. In sum, then,

$$\frac{dW}{dt} = aN^2 - bW. \quad (2)$$

An alternative form for the second equation specifies that the rate at which groups send out war parties is proportional to the product of population density and warfare intensity. This leads to a redefinition of the first term on the right-hand side of (2) as follows:

$$\frac{dW}{dt} = aWN - bW. \quad (3)$$

The two models (as specified by equations 1 and 2, and by equations 1 and 3) have similar dynamic behaviors, and both achieve a single equilibrium that can be approached in an oscillatory fashion. In figure 19.1, we graph the behavior of the system described by equations 1 and 2 for some arbitrary parameter values, first through time (figure 19.1a), and then in the phase plane relating population size to incidence of warfare (figure 19.1b). From these we can see that (1) high levels of warfare eventually take a toll on population density, (2) decreasing population density eventually causes warfare to subside, and (3) low levels of warfare eventually result in higher rates of population growth. In the absence of changes in K (carrying capacity), the two variables eventually find a stable equilibrium after exploring the phase space in a counterclockwise spiral of decreasing amplitude. An important additional point is that if contemporaneous values of N and W are sampled from the series in figure 19.1a, they will have only a very slight relationship when in fact we can see that increasing incidence of warfare has a deterministic negative impact on the *rate of change* in population growth, and population

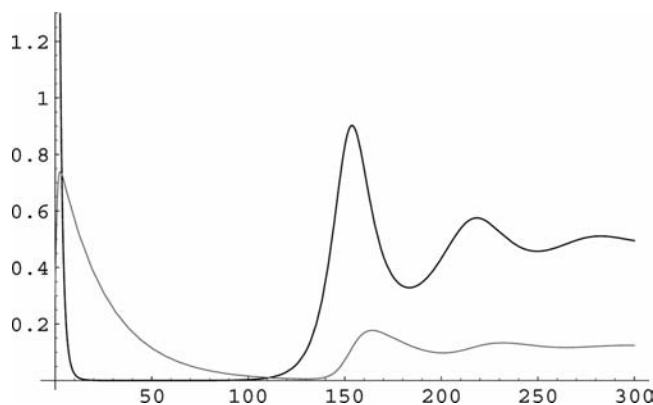


FIGURE 19.1A The relationship of N (black line) and W (red line) through time for the system of equations (1) and (2); values for N and W on the y-axis, time units on the x-axis. Parameter values: $r = .13$, $a = .02$, $b = .04$, $K = 8$; initial conditions $N = 5$, $W = .3$.

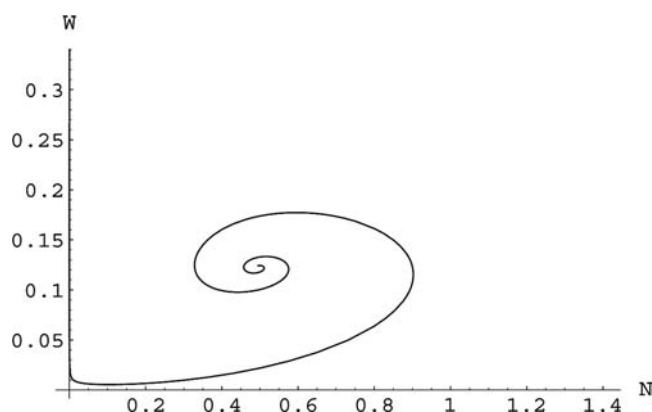


FIGURE 19.1B Relationship of N and W . Time begins at the periphery of the spiral and moves toward the equilibrium point at the center. Parameters and initial conditions are as in figure 19.1a.

growth affects the rate of change in warfare positively (Turchin and Korotayev 2006, 5).

This model, they suggest, will not apply to external warfare. Among relatively complex societies, such warfare may be due to other considerations, notably territorial expansion. Presumably, a related assumption is that the area examined is, or can be treated as, a closed system with no important immigration or emigration. We will attribute poorness of fit of this model in some portions of our sequence to our failure to meet these assumptions.

To examine how well this model fits the prehispanic Pueblo case in our well-studied portion of the northern U.S. Southwest (figure 19.2), we need estimates of N (population density), W (incidence of warfare), K (carrying capacity), the coefficient of instantaneous population growth r , and the proportionality constants a , b , and c . In the following sections we develop each of these in turn.

THE VILLAGE ECODYNAMICS PROJECT

“Village” is an interdisciplinary project to describe and model the dynamics of settlement growth, aggregation, and abandonment in the 1,800-km² area of southwest Colorado shown in figure 19.2 between 600 and 1300 CE. It is a joint undertaking of archaeologists at Washington State University and Crow Canyon Archaeological Center, hydrologists at the Colorado School of Mines and BBL, Inc., computer scientists at Wayne State University and the University of Windsor, and several other researchers and disciplines.

BACKGROUND: CULTURE HISTORY

The high, well-watered lands of the northern and eastern portions of the study area, which represent the regional frontier for ancestral Pueblo populations, generally trend down in elevation and become more xeric to the south and

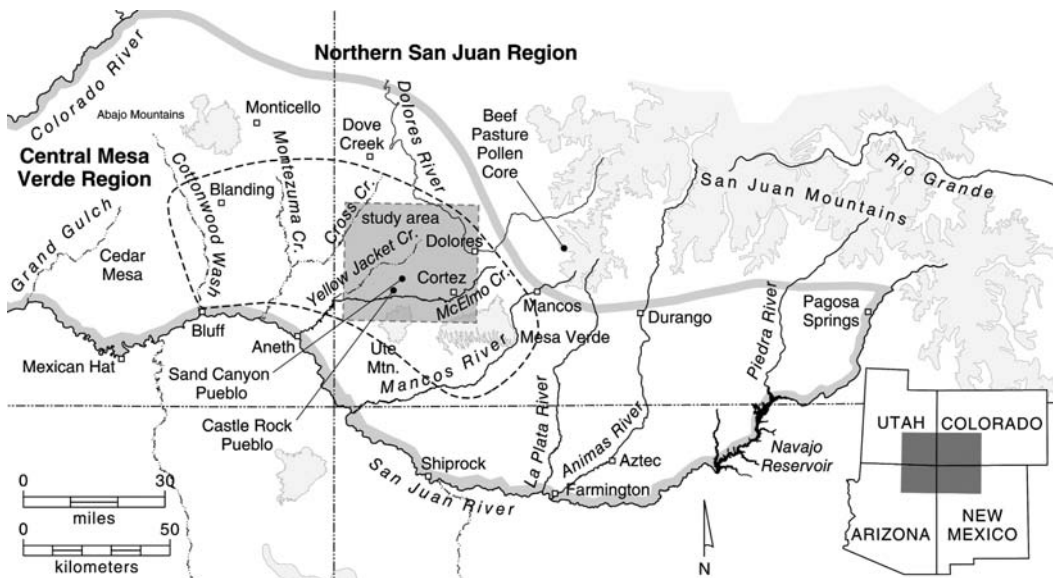


FIGURE 19.2 Location of the Village Ecdynamics project area in southwest Colorado.

east. The high *cuesta* of Mesa Verde intrudes into our study area from the southeast. Farmers made their way into our region slightly before 600 CE, and this area is rightly famous (e.g., Flannery 2002) for some of the earliest villages in the Southwest, dating to the late 700s and 800s, thoroughly studied by the Dolores Archaeological Project (Breternitz, Robinson, and Gross 1986). The study area was partially depopulated under cold, dry conditions circa 900. A major population influx in the mid- to late 1000s brought with it the earliest structures reminiscent of the great houses of Chaco Canyon and its surrounding area, some 170 kilometers south-southeast of our study area. A few archaeologists (e.g., Wilcox 1999) interpret Chaco's fluorescence following an internal reorganization around 1030 as that of an expansionist, tributary state, though many others are more cautious; see contributions to Lekson (2006) and Kohler and Kramer Turner (2006) for the state of the debate. The polity centered on Chaco Canyon went into decline in the mid-1100s, causing turmoil in our study area, though study area populations continued to grow. In the mid-1200s, many community centers in our area relocated to canyon head locations, and many of these are walled. Local

populations began to decline by about 1260, and the area was completely depopulated by farmers sometime in the 1280s. For much more detail on this sequence please, consult Lipe, Varien, and Wilshusen (1999) and Varien and Wilshusen (2002).

PALEODEMOGRAPHY (N)

Scott Ortman, Mark Varien, and others at Crow Canyon Archaeological Center and Washington State University reconstructed the paleodemographic trajectory for our study area beginning from a massive review of all existing site forms along with some new survey. Using a Bayesian framework, Ortman developed a method for combining chronological and demographic information that efficiently exploits the information available from previous excavations, ceramics on site surfaces, tree ring dating, architectural characteristics, site locations, and various measures of site size to arrive at estimates of momentary numbers of households in known habitation sites for each of fourteen periods from 600 to 1300 CE in which our study area was occupied by farming populations (Ortman et al. 2007). Using three slightly different techniques, Varien et al. (2007) extrapolated from these sample numbers to estimate the total

TABLE 19.1. *Summary Data for Chronology, Population, and Carrying Capacity (K)*

VILLAGE MODELING PERIOD	BEGIN (CE)	END (CE)	MIDPOINT (CE)	TRADITIONAL PECOS PERIOD	TOTAL MOMENTARY HOUSEHOLDS ^a	FLUX	CARRYING CAPACITY ESTIMATE (K)
—	600			BIII	0		—
6	600	725	663	BIII	304		1,580
7	725	800	763	PI	326		1,580
8	800	840	820	PI	836	180	1,580
9	840	880	860	PI	1,030		1,580
10	880	920	900	PII	370	−477	1,580
11	920	980	950	PII	289		1,515
12	980	1020	1000	PII	653	92	1,345
13	1020	1060	1040	PII	671		1,430
14	1060	1100	1080	PII	1,385	110	1,635
15	1100	1140	1120	PII	1,940		3,234
16	1140	1180	1160	PIII	2,077		3,234
17	1180	1225	1203	PIII	2,326		3,234
18	1225	1260	1243	PIII	3,234		3,234
19	1260	1280	1270	PIII	1,770	−1,430	1,770
—		1300			0		1,400

^aUsing Varien et al.'s (2006) method 3.

NOTE: Study area is colonized by farmers shortly before 600 CE and is completely depopulated by shortly after 1280. Periods 1–5 are reserved for nonfarming groups not discussed here.

population of households in the study area. To keep the following analyses as simple as possible, as our estimate of N in the following, we use the estimates for the population of contemporaneous households provided by their “method 3,” which they also prefer.³ Table 19.1 reports these estimates by period.

CARRYING CAPACITY (K)

Estimates of carrying capacity for human populations are notoriously difficult to make because humans are so flexible in their behavior. One well-studied class of flexibility is economic (or subsistence) intensification; in the case at hand, we are particularly interested in agricultural intensification, which we define as either working longer or implementing new techniques to derive the same (or more) per capita production from domesticates under population increase or environmentally imposed restrictions on production. Similar processes are described by numerous authors, beginning in anthropology notably with Boserup (1965), but in fact finding

intellectual parentage with the British political economist David Ricardo, who recognized that increasing input into production generally succeeds in increasing yield, but only at a decreasing rate. In the case analyzed by Boserup, agricultural intensification provoked by population increase involved both shortening the fallow cycle and introducing the plow; the resultant intensive agricultural system required more hours per person per week. The initial Neolithic domestication of plants and animals is frequently considered an example of subsistence intensification (e.g., Wright 1994). Intensification can involve switching to less desirable animal or plant species if more desirable and easier-to-exploit species become depleted.

Even ignoring the complexities of intensification, it is not clear how to estimate human carrying capacity for a given environment. Five main difficulties stand out. First, humans are flexible in their use of space, and unless prevented by considerations of ownership or distance, they tend to switch patches to maximize

return to effort as returns from patches currently exploited decrease to the point where equal or better returns on effort are available elsewhere. Farmers, however, are more territorial than implied by this construction because of their greater investment in land improvements and facilities, and they usually end up distributed across space according to the “ideal despotic distribution” (Sutherland 1996) in which late arrivals are forced into less desirable patches. This is hard to deal with outside of a dynamic spatial model.

Second, humans need to meet their subsistence requirements within the context of also meeting other needs (in our model, they consider water, fuels, protein from hunting, and carbohydrates from agriculture). These constraints may put some areas outside of practical limits for exploitation. Third, all the calories or protein on a landscape are not available to people, whether because of food taboos or because the cost of exploitation is greater than the return, as for low-density or hard-to-process foods. Fourth, especially in the part of the world we are discussing, interannual climatic variability in temperature and precipitation amounts and timing can have significant effects on production, but the magnitude of these effects is hard to estimate. Finally, beyond the consequences of territoriality discussed earlier, human use changes the environment in complicated ways. Some usage (e.g., harvest of woods for fuel and construction and deer hunting) certainly degrades the environment for those purposes at least temporarily, but the cleared land and reduction in agricultural pests might boost production for agriculture.

The agent-based simulations we are developing in the Village project provide at least partial solutions for these problems. (Kohler, Gummerman, and Reynolds [2005] review in a nontechnical way how agent-based modeling is assisting our interpretations of southwestern prehistory.) It is beyond the scope of this chapter to explain in detail how the model works (see Cowan et al. 2006; Johnson, Kohler, and Cowan 2005; Kohler et al. 2007). Most relevant here is that we track caloric production and consump-

tion carefully in the model, “charging” expenses for hunting, gathering of fuel and water, agricultural fieldwork, and basic metabolism, against the production and storage achieved by each household. Production of maize is affected directly by climatic variability, as is growth of woody biomass for fuels; we model densities of the three most important prey species (cottontail, jackrabbit, and mule deer) as a function of the growth of the species they graze or browse (and this vegetation itself is also affected by climatic variability) and the level of human predation. Household efforts to acquire adequate protein and calories may be assisted by processes of generalized exchange (among kin) and balanced reciprocity (among nonkin neighbors).

Base human mortality and fertility parameters are taken from Weiss’s (1973, 156) 27.5-55.0 model table; in the simulations used here to develop estimates of *K*, favorable caloric and protein balances increment natality probabilities and decrement mortality rates, by 10 percent relative to that table. On the other hand, an unfavorable protein or caloric balance returns those rates to those in the life table. Inadequate caloric consumption that cannot be immediately offset by new production, existing storage, or exchange causes households to try to move to better areas, but households have no way to exit the study area. When relocating, households choose from among the cells that are favorable for agriculture and are underoccupied, that cell from which it will be least calorically expensive to satisfy their water, fuel, and hunting needs. Households may perish from lack of calories if relocation or buffering techniques are unsuccessful, but in the simulations shown here, inadequate protein consumption by itself never kills a household (though it may increase the likelihood that its individual members may perish).

As a result, the populations achieved by our model households can be regarded as rough estimates of carrying capacity for populations farming maize and hunting deer, rabbit, and hare, under the parameters used in each particular run of the simulation. Our households are capable of limited intensification: they can work

harder (e.g., by going farther to hunt or gather fuels as the need arises, or by tending more plots of maize if they have enough workers), and they can switch prey species, among the three that we model, in response to changing local availability.

One important thing that they cannot do in the current simulations, though, is to domesticate and raise turkey. We know that domesticated turkey becomes an increasingly important part of the diet in some sites in the northern Southwest in the 1000s, and then it continues to increase in importance through time in most areas, including our own, replacing declining artiodactyls (chiefly mule deer) (Driver 2002).

Our current simulations show that when human population numbers reach those achieved in our area in the mid-800s, they significantly deplete deer (Cowan et al. 2006). In the absence of turkey domestication or greatly increased long-distance hunting of deer, or other accommodations, the inhabitants of this landscape may well be protein limited at the considerably larger population sizes they achieved in the 1100s and 1200s (table 19.1). Decreasing protein on the landscape (and increasing energy required to hunt for it) contributes to a general decline in agent populations in most simulations. Although agent populations could, most likely, be higher in later periods were our agents able to raise and eat turkey, it is impossible for us to estimate how much higher without completing a detailed analysis of the costs and benefits at the level of the household, and simulating the result.

For the purposes of this chapter, we take, where possible, estimates of *K* from agent-based simulations in which various parameter values are set to maximize the number of households on the landscape (while not exceeding what we view as plausible values for those parameters). Even so, for periods 15–18, our population estimates from the archaeological record are higher than those achieved by our agents, probably due to the intensifications discussed earlier that we don't model. In those cases, we use the highest actual population estimate as the *K*, given abundant evidence (rehearsed in Kohler 2000) that these populations were under considerable

stress at those levels. For all of the first five periods (periods 6–10), we assign *K* the highest simulated agent counts achieved in any of these periods, since the agent numbers early in the sequence are limited by the fact that we begin our simulations with two hundred immigrant households in the year 600.

INCIDENCE OF INTERNAL WARFARE (W)

In the absence of a written record, archaeologists infer warfare and conflict indirectly from a variety of evidence, including site location and size, frequency of defensive features such as walls, artifacts with potential aggressive or defensive function, and skeletal trauma. Here we develop only one of these lines of evidence, skeletal trauma.⁴ To make the database as large as possible, we extended the collection of these data beyond the boundaries of the study area to include the area just south of Ute Mountain, all of Mesa Verde National Park, and on south to the Colorado–New Mexico border, and into southeastern-most Utah, as far south as the San Juan River. We believe that cultural processes were similar enough across this somewhat larger region that this should not distort our findings.

The kinds of trauma used to identify violence consisted of fractures (healed or not) to the ulna and/or radius, which most likely resulted from a blow to the arm raised in defense. We also considered perimortem and antemortem cranial fractures as warfare-related trauma. However, not all cranial fractures are likely to result from such circumstances. Accidental falls are the most common source of cranial trauma among children and the elderly (Hussain et al. 1994), and facial fractures to the nasal bone or occipital region are more likely to occur during spontaneous interpersonal violence (Walker 1997). Thus, such fractures were not included in this analysis. Finally, we included the cultural modification and disarticulation of human remains (as might result from cannibalism) encountered at sites such as the well-known Cowboy Wash (Billman, Lambert, and Leonard 2000) and Aztec Wash sites (Dice 1993), Mancos 5MTUMR-2346 (White 1992), and Castle Rock Pueblo

TABLE 19.2. *Raw Data and Calculation of Instability Index W*

PERIOD	MIDPOINT	X	N	X/N	A	B	μ''	RAW INSTABILITY INDEX	W (FINAL VERSION)
6	663	2	11	0.1818	-0.12119	-0.4058	0.1794	0.1038	0.1038
7	763	1	10	0.1000	-0.12119	-0.4058	0.0928	-0.0162	0.0000
8	820	0	6	0.0000	-0.12119	-0.4058	-0.0222	-0.3231	0.0000
9	860	3	55	0.0545	-0.12119	-0.4058	0.0529	0.0358	0.0358
10	900	6	18	0.3333	-0.12119	-0.4058	0.3365	0.3154	0.3154
11	950	0	13	0.0000	-0.12119	-0.4058	-0.0097	-0.1071	0.0000
12	1000	5	20	0.2500	-0.12119	-0.4058	0.2506	0.2220	0.2220
13	1040	17	70	0.2429	-0.12119	-0.4058	0.2430	0.2353	0.2353
14	1080	24	45	0.5333	-0.12119	-0.4058	0.5370	0.5387	0.5387
15	1120	44	108	0.4074	-0.12119	-0.4058	0.4083	0.4065	0.4065
16	1160	30	35	0.8571	-0.12119	-0.4058	0.8668	0.8894	0.8894
17	1203	4	34	0.1176	-0.12119	-0.4058	0.1159	0.0915	0.0915
18	1243	6	75	0.0800	-0.12119	-0.4058	0.0789	0.0673	0.0673
19	1270	51	121	0.4215	-0.12119	-0.4058	0.4223	0.4210	0.4210

NOTE: x is the count of skeletal remains (per individual) with warfare-related trauma, and n is the number of individuals. We used Bayes's theorem to generate an improved estimate of π from the observed sample proportion p (where $p = x/n$, as explained in Cole 2007). See also Robertson (1999) for discussion of this method.

(Kuckelman 2002b). We did not count other types of fractures to other parts of the body (the most common being rib fractures) because we could not confidently determine that these were not accidental in origin.

Cole (2007) collected these data from the literature and not via direct examination of the materials (some of which have been reburied). The kinds of sources used largely consisted of site reports and “gray” literature. She could usually determine the age and sex from these reports; they also usually included a detailed description of any skeletal trauma and pathological conditions, and the position and location of interment. Thus, she was able to decide which kinds of trauma to attribute to violence—and her determination did not necessarily agree with that of the original author. She used Turner and Turner's (1999) *Man Corn* as a secondary source when considering the cultural modification and disarticulation of human remains. Large-scale excavation projects such as the Dolores Archaeological Program, the Towaoc Canal (Reach III), the Ute Mountain Piedmont project, and the Sand Canyon Archaeological Project provided most of the data.

Table 19.2 shows the n of individuals for each period, the number of those with skeletal trauma suggestive of warfare (x), and the resultant estimate of W (slightly refined using Bayesian techniques and converting negative values to zero; see Robertson 1999, including the formula in his note 2] for a discussion of the method used here).

Turchin and Korotayev considered W to be warfare intensity or frequency, so the death rate to warfare cWN (in equation 1) is assumed to be directly proportional to its intensity. In the same way, we consider our estimate of W to measure intensity of conflict, and we therefore must make the same assumption—that this intensity will be directly proportional to a death rate from warfare.

COEFFICIENTS r , a , b , AND c

The instantaneous coefficient of population growth (Odum and Barrett 2005, 239) is the growth rate achievable in the absence of limiting factors. We calculate a minimum estimate for r by finding the value required for 304 colonizing households present in our study area by about 663 CE to increase to 1,030 households

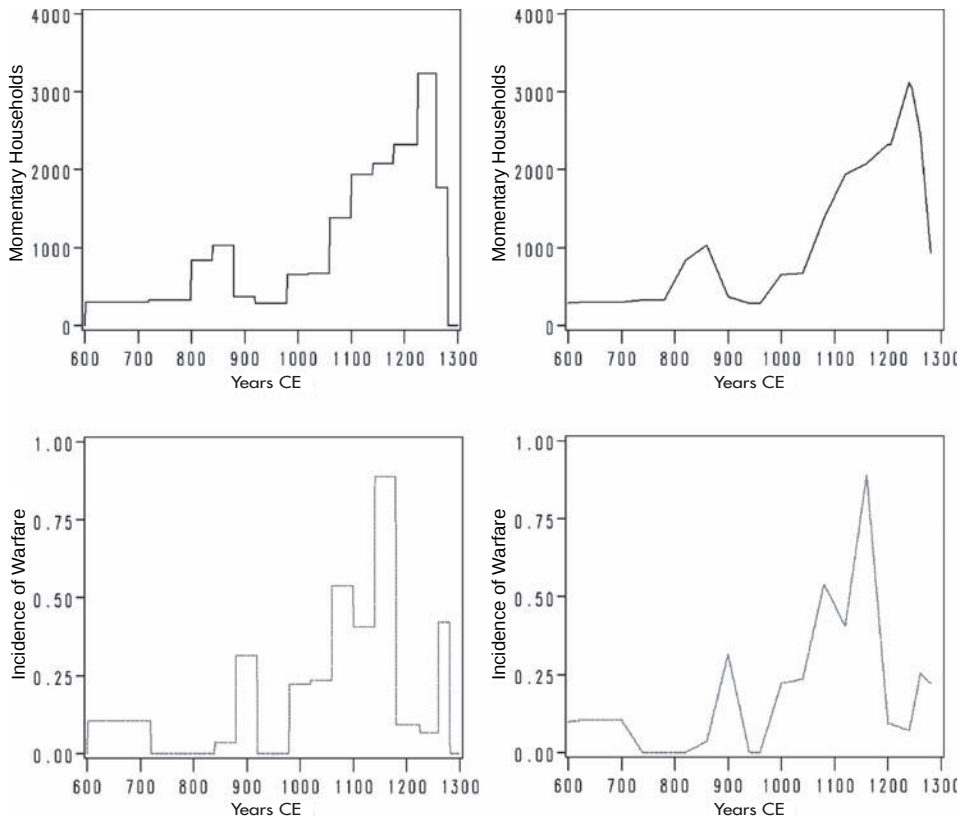


FIGURE 19.3 Unsmoothed (left column) and smoothed (right column) versions of N and W .

by about 860 CE (table 19.1), leading to an estimate of 0.006 (annual) for r . In our attempts to fit Turchin's model to our data, we used values for r ranging from 0.007 to 0.014 in recognition of the fact that the maximum attainable r for human populations is higher than 0.006, perhaps as high as 0.02 (Ehrlich and Ehrlich 1970). We also added fluxes to the model at various points where we identify growth in excess of that achievable through in-place processes or emigration (see table 19.1; Varien et al. 2007). We estimate best-fit values for the proportionality constants a , b , and c in the context of fitting the models to both the population and the warfare intensity data.

EVALUATING THE MODEL

There are several ways to determine how well Turchin and Korotayev's models fit these data from southwest Colorado. First, we can inspect

the time series of N and W (figure 19.3) to see if they bear any resemblance to the relationships claimed in the models (figure 19.1a). These two series are graphed to a common scale in figure 19.4, after smoothing using forty-year running means, following Turchin's procedure. Discounting the slightly higher-than-expected W in our earliest period, we see that in the first cycle of this historical sequence, N peaks before W , just as expected, and then falls in the context of high W , as expected, and then W falls, too, just as N begins to rise again. This is all as it should be. But between about 1000 and 1200, increases in W lead increases in N , very much contrary to the model.

Another way to evaluate the models is to inspect the phase plot of N against W (once again after smoothing), keeping in mind the shape proposed by the model (figure 19.1b). The plot generated from our data (figure 19.5) shows the expected relationships from the 600s through

FIGURE 19.4 Graph of standardized, smoothed population (N , black) superimposed on standardized, smoothed warfare frequency (W , red).

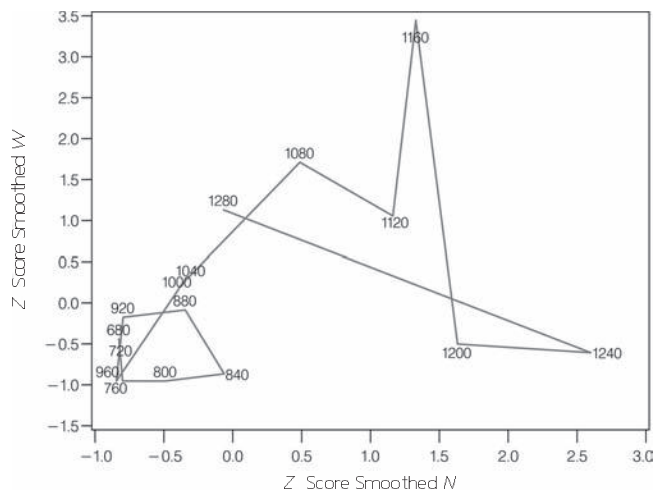
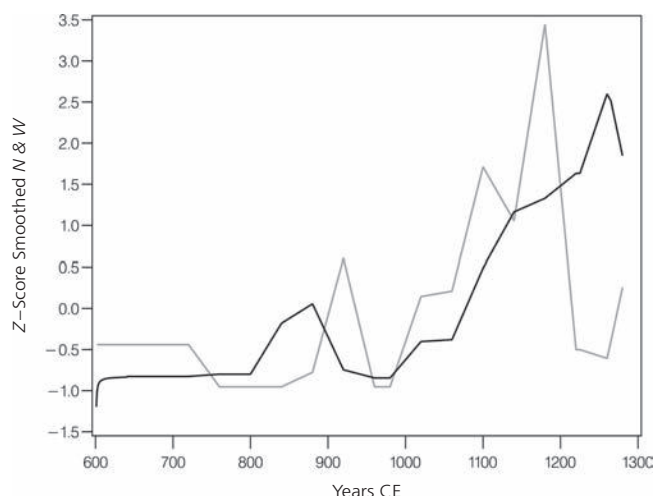


FIGURE 19.5 Phase plot of N and W (after smoothing and standardization) using data from southwest Colorado.



the mid-900s, with mild reversals not far outside of the expected pattern through 1040. There is a strong reversal of the expected pattern for the next three data points (1080–1160) with a return to the expected pattern in the 1200s, albeit in a different region of the phase space.

A third way to evaluate the models is to realize that, if the lag suggested by the models in the effect of increasing N on W in the actual record is about forty years in length, then we ought to be able to see a strong positive relationship between N , lagged forty years, and W . Here, once again, we replace the observed values for N and W with forty-year running means for both, sampled at forty-year intervals. Figure 19.6 shows that there is indeed a positive

relationship, but not a significant one, at least when all periods are included. The data points for the late 1000s and mid-1100s are particularly strong outliers. Once again, the 1200s appear to represent a consistent regime, but one that is very different from the regime in place from the 600s to 900s.

Finally, and most rigorously, we can fit values of a , b , and c for the models, using the time series of our empirically known N and W (table 19.1), and then assess the goodness of fit obtained using the parameters so derived. Here we consider the model proposed by equations 1 and 3 only, since initial exploration showed that we obtained better fits with this model than the one in equations 1 and 2. We start by assuming that initially, at year 600, the population size is

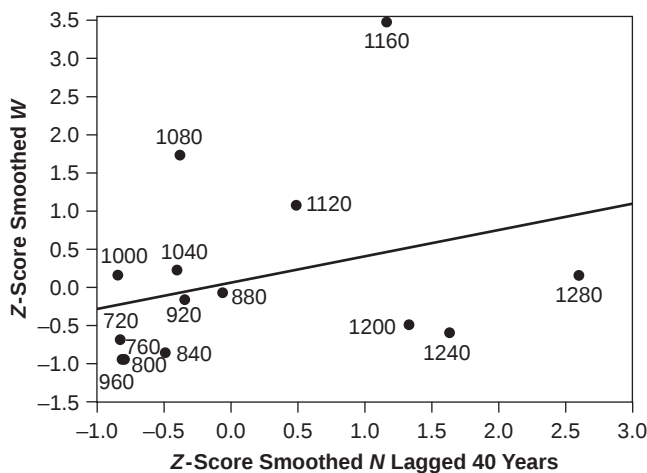


FIGURE 19.6 Regression of $W[t]$ on $N[t-1]$: $r^2 = .09$, $p > F = 0.27$.

$N_0 = 152$ households, and the intensity of warfare is, as given in table 19.2, $W_0 = 0.0519$. With this assumption and known values for r and K , we estimate the remaining parameters a , b , and c using the weighted least-square regression. Let us define the functional

$$J(a, b, c) = \sum_{i=1}^n \omega_N (\log(N_i) - \log(N_{data,i}))^2 + \sum_{i=1}^n \omega_W (W_i - W_{data,i})^2,$$

where n represents the number of data points (in our case, the seventeen time periods) indexed by i , N_i , and W_i are the population size and war intensity at times t_i predicted by the solution of equations 1 and 3, $N_{data,i}$ and $W_{data,i}$ represent the data values for the populations and for warfare at times t_i , ω_N and ω_W , are additional weights that ensure that we give equal influence to both the population, N , and the war intensity, W , observations. They are given by

$$\omega_N = \frac{1}{\sigma_N^2} = \frac{1}{\frac{\sum_{i=1}^n (N_{data,i} - \bar{N}_{data})^2}{n-1}},$$

and

$$\omega_W = \frac{1}{\sigma_W^2} = \frac{1}{\frac{\sum_{i=1}^n (W_{data,i} - \bar{W}_{data})^2}{n-1}},$$

where $\bar{N}_{data}$, $\bar{W}_{data}$ are the average values of the measured data, N and W . Differences in logarithms for the population, N , rather than differences in numbers were used to accommodate the changes in size (large population sizes from 1080 to 1280, vs. small populations in the 640–880 period). We gave equal weight to the warfare intensity data and to the population data in the minimization algorithm. The optimization analysis was performed using the Nelder-Mead nonlinear iterative routine (fminsearch) and an ordinary differential equation solver (ODE45) in Matlab.⁵ The resultant values for a , b , and c are shown in the captions of figure 19.7.

Of interest here is that the fitted values for W far exceed those observed in the 1200s and even exceed the possible values for this parameter, which are from 0 to 1. The model cannot accommodate both the very high W and moderately high N values seen in the 1000s and 1100s with the very high N and moderate or low W values experienced in the 1200s. This emphasizes both of these departures as things that need to be explained.

DISCUSSION

We find relatively strong support for the version of the Turchin-Korotayev model represented by equations 1 and 3 during the first population cycle, when exogenous factors appear to have

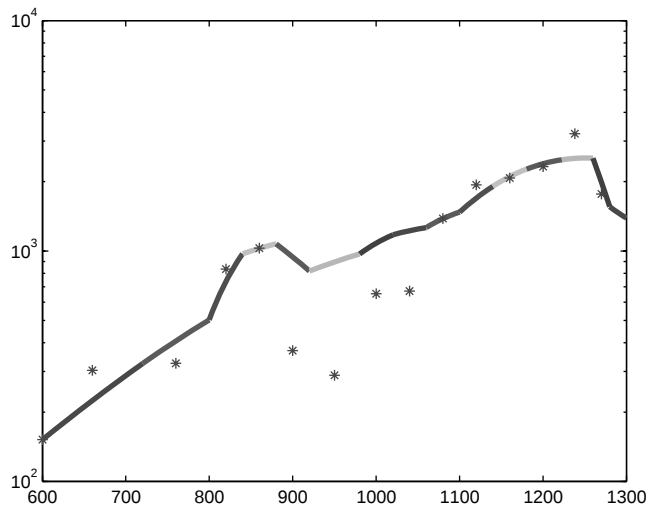
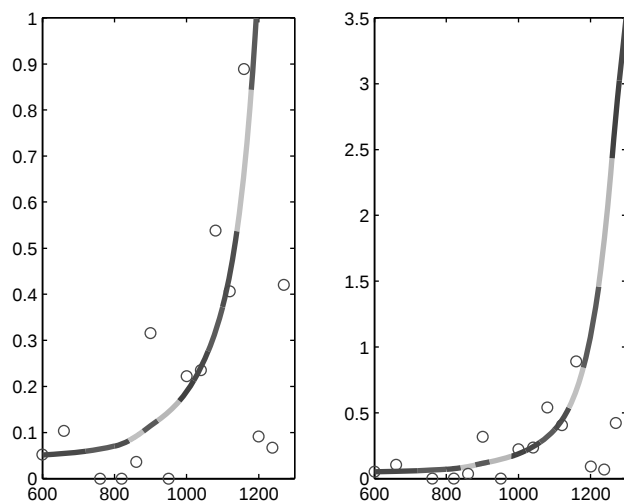


FIGURE 19.7 Top: N (note log scale) from data (blue asterisks) against best-fit model for equations 1 and 3 (colored line). Bottom: W from data (blue circles) against best-fit model for equations 1 and 3 (colored lines). (below) On the left we graph W in its possible range, from 0 to 1.0. On the right we graph the actual estimated values, which exceed 1 in the 1200s. Using r between .007 and .014, best-fit values for the unknown parameters a , b , and c are $a = 0.00011$, $b = 0.003$, $c = 0.006$, and the goodness of fit as measured by the residual $(ESS_{\log(N)} + ESS_W)$ is 2.98.



been weak. The rise and fall of population and frequency of warfare in this first cycle do not require any explanation beyond that provided by the model, although we must still elucidate the mechanisms underlying this relationship. The apparent failures of the model during the second population cycle may be due to the relative strength of exogenous factors in our area, discussed later.

Why are population size and warfare linked in the manner proposed by the model, and seen in our area from 600 through the 900s? Explaining why increased warfare might eventually cause decline in population is relatively easy. First, there are of course some direct

deaths due to warfare that affect present and future population size. Second, Divale and Harris (1976) suggested that protracted warfare may lead to female infanticide, as parents attempt to raise more boys to become warriors. Such female infanticide, if present, can perhaps be identified in young adult sex ratios if we look carefully, and it would, of course, depress current and future population size. Third, to the extent that warfare stimulates aggregation, and aggregation promotes disease, warfare may depress populations through a back channel. Fourth, it is possible that prolonged conflict, by stimulating aggregation, leads to population distributions with respect to resources that are

so inefficient that they may even suppress reproduction slightly. We are currently examining this possibility by comparing agent distributions from our simulations, which are efficient in their use of space and resources, to the actual household distributions from the archaeological record (Kohler et al. 2007). Finally, we know from much sad contemporary experience that people will leave war-torn areas if they are able to do so. Therefore, population decline in periods of violence may be due in part to flight from danger to safety.

In the absence of these conditions, on the other hand, populations increase given appropriate levels of production.

It is only slightly more difficult to detail the mechanisms by which more people on a landscape eventually cause more warfare. Obviously, absent innovations to increase production (technical in nature, or sociopolitical, having to do with the organization of production or distribution, or the means for conflict resolution), more people will lead to more conflicts over (fixed) resources. But more subtle mechanisms may also be at work. More people increase the relative importance of the social milieu, and warfare is a time-honored path for achieving social status and wealth, either through reputation for bravery in battle that becomes generalized to other social domains or through land or chattel acquired in victory.

IMPLICATIONS FOR LOCAL CULTURE HISTORY

This analysis suggests some novel explanations for various aspects of the prehistory of this area, including the following:

- The onset of aggregation in this area in the Pueblo I period in the late 700s and the mid-800s apparently takes place in a climate of little violence, which weakens warfare as a general explanation for early aggregation in the Southwest.
- The depopulation of this area at the end of the Pueblo I period may be as closely related to a rising incidence of warfare, and inhabitants' desires to leave those conditions behind, as it was to unfavorable climatic conditions.
- The first increases in violence that are unanticipated by the model occur in the late 900s and early 1000s, well before the earliest structures in our area that look "Chacoan" (Lipe and Varien 1999, 272). This anomaly pointed up by the model suggests that we need to look for external influences before they become obvious as Chacoan-style architecture. Perhaps sites like the Dobbins stockade (Kuckelman 1988), the Dripping Springs stockade (Harriman and Morris 1991), the stockaded Ewing Site (Hill 1985), and Two Raven House (Hayes 1998)—all dating to the early 1000s—represent resistance (ultimately unsuccessful) to Chacoan expansion.
- The circa 1080s immigration (spanning the period from 1060 to 1100) represents the first successful Chacoan intrusion into this area—quite possibly achieved via violence given contemporaneous values for W —followed by a second wave of consolidation in the early 1100s. Several stockaded settlements have also been documented for the mid- to late eleventh century (Mustoe Site [Gould 1982], Yellow Jacket [Lange et al. 1986], Casa Bisecada [Morris 1988], and Roundtree Pueblo [Morris 1991]). The slight decrease in violence in the early 1100s, if real, represents as close to a "Pax Chacoensis" as our area ever experiences.
- The collapse of the Chacoan system in the mid-1100s brought violence to unprecedented levels in our area, perhaps in the form of score settling as old (but apparently resented) power structures fell apart. Chaco's decline or demise was accompanied by population decline in the Chacoan heartland of the Central San Juan Basin, which is hit hard by a long mid-1100s drought, though not in our area, where climatic conditions were slightly more favorable for maize production (Kohler et al. 2007).
- The surprising and sudden reappearance of much less violent conditions circa 1200 returns our area to a regime in which

population and warfare were again related as proposed by the model, except that warfare incidence was much lower than would be anticipated by the model, given its relationship to population in the first population cycle. Although this appears to be in sharp contrast to what others have suggested for the level of warfare in the 1200s Southwest, this is not necessarily the case. The example of direct evidence most often used to infer violent conditions consists of the village-wide massacre at Castle Rock Pueblo that occurred in the late 1200s. Indirect evidence often cited for high levels of conflict in the 1200s also includes movement to inaccessible/defensive locations at canyon rims or in alcoves and near water supplies, which was largely a mid-1200s phenomenon. Evidence for violence in the early 1200s, then, is rather limited. This is all the more surprising because the early 1200s were cold, and maize farming must have been uncertain in many upland and northern areas; poor and uncertain production have been used as predictors for warfare in this area or its surrounding region by Lekson (2002), Kantner (1999), Kuckelman (2002b), and LeBlanc (1999, 34–35). Perhaps a new political model emerged out of the chaos of the mid- to late 1100s that was able to restore more peaceful conditions. Given the effects expected by scalar stress theory on political organization in these populations, which were constantly increasing in size from the mid-1000s through the mid-1200s (Johnson 1982), it seems likely that this marked decline in violence is due to the local emergence of structures—such as alliances or confederacies among communities—that had wider spatial, demographic, and political scope than the community-level organizations that probably dominated the first population cycle. These structures were by inference able to quell violence within their scopes of control—at least until the late 1200s.

- Finally, recurring violence in the late 1200s is predicted by the model to contribute to the depopulation that terminates occupation of this area by Pueblo peoples.

It has been a puzzle to explain the history of aggregation in our area. It is clearly connected with population size, but people continued to live in aggregated settings circa 900 and 1270, even as populations were decreasing. The lagged effect of population size on prevalence of violence assumed by the model and visible in our data suggests that aggregation for protection would continue to be important after population peaks. On the other hand, initial aggregation (e.g., in the late 700s and mid-800s, and perhaps again in the mid-1200s, though this case is much more problematic) appears to take place in an atmosphere in which warfare-related trauma was unusual. We suggest that initial phases of aggregation were often connected with economic and political factors scaling with population size, whereas retention in aggregates at and after population peaks was due, at least in part, to considerations of safety.

IMPLICATIONS FOR EVOLUTIONARY ANALYSIS

Since the Turchin model posits a close association between warfare and population size, it is inescapably relevant to evolutionary concerns with population-size effects on cultural transmission (e.g., Henrich 2004; Shennan 2000).

More fundamentally, warfare can be an important mechanism for cultural group selection (which need not involve extinction of demes). If the cycles identified by Turchin take place repetitively over evolutionary time scales in patchy environments among competing groups with differential group success, and if these processes are typically linked with migration to new patches by some groups as they are in the record discussed here, we have the key ingredients required to make cultural group selection a strong force in human cultural evolution. Such conditions can promote the evolution of altruistic behaviors such as bravery in warfare that may be

deleterious to the individual but benefit the group and contribute to its success relative to its competitors. Moreover, the prosocial but individually costly behaviors, norms, and values that can become part of cultural practice via this mechanism need not be related to warfare (Boyd and Richerson 1985).

CONCLUSIONS

Like any model that works reasonably well, the Turchin model has two main strengths. First, for those regions of the problem where it fits, it tells us that no additional causal processes are needed to explain the phenomena of interest, so long as we can identify satisfactory mechanisms for the processes invoked and can with reasonable certainty eliminate equifinality (the possibility that *other* models might explain the phenomena equally well). We also learn from those circumstances where the model fails, since those regions of the problem require additional or different causal processes.

For the cultural-historical case discussed here, the relative success of the model suggests that absence of warfare enhances population growth but that high population sizes tend to entrain violence, and once violence becomes prevalent, it tends to decay slowly because of revenge effects. In the record discussed here, warfare may be a significant factor in the cessation of population growth in the mid-late 800s, and its prevalence may contribute to declines in population, including emigration, around 900 and in the late 1200s. Except when considering its possible effects on settlement location, southwestern archaeologists tend to think about warfare as a dependent variable. This analysis strongly suggests that it has other independent effects as well.

On the other hand, we also see that these tendencies can be overridden (climate permitting) by strong sociopolitical factors that can result in population growth even amid violence, as experienced from the late 900s through the mid-1100s in the area discussed here. The fact

that our model does not explain the relationship between population and warfare during this period, and that the Ember and Ember model (1992) used by Lekson (2002) to explain warfare in the Southwest fails in this same area for the early 1200s, demonstrates that, as Keeley (1996, 17) suggested, “no complex phenomenon [such as war] can have a single cause.”

The poor fit of the model during the periods of Chaco expansion, control, and collapse is not unanticipated, however, given that the model is not designed to apply to external warfare motivated by desire for territorial expansion—as might have been the case for Chaco. Minimally, the disjunction between the predictions of the model and the record has the virtue of throwing into relief the drastic change in the relationship between warfare and population caused by Chacoan influence, *whatever* that was. Secondly, the 1200s return to a relationship between violence and population more in line with that predicted by the model, but with less violence than we would have expected given the relationship between violence and population in the first cycle, makes it possible for us to suggest the probable form of the local political regime in our area during the final century of its Pueblo occupation. In sum, the Turchin model identifies a simple set of relationships that has explanatory power when the conditions required by the model are met. Perhaps equally gratifying—and demonstrative of the potential of model-based archaeology as defined by Kohler and van der Leeuw (2007)—the model is almost as helpful even when it does not fit.

On the somewhat less positive side, we suspect that the situations where this model works well may be few and temporary; at least in the post-Neolithic world, we cannot often find places and times where exogenous factors are of little import for long periods. Specifically, as in the case reviewed here, the relationships within the model are subject to being upset, or at least complicated, by the increases in geographic scope and sociopolitical scale typical of post-Pleistocene societies when viewed over long

enough periods. Perhaps the conditions required by the model would be more frequent in the pre-Neolithic world.

Acknowledgments. We thank Bill Lipe for comments on the prehistory of Mesa Verde region; Scott Ortman for his help with Bayesian estimates; Crow Canyon Archaeological Center for the use of its library to compile the statistics on warfare; Doyne Farmer of the Santa Fe Institute for his helpful discussion of assessing the fit of the Turchin-Korotayev models; the Santa Fe Institute (SFI) for its congenial atmosphere; NSF SBE 0119981, which helped fund the development of the agent-based model discussed here and provided funding to build and organize the database of archaeological sites with which we compare the model; WSU for sabbatical support for Kohler; and audiences at Crow Canyon, SFI, the University of Calgary's Chacmool conference, University College London's CEACB conference, UBC, and Yale, who heard trial versions of various portions of these materials. Finally, we are grateful to Stephen Shennan for his invitation to participate in the very interesting CEACB meeting and in this volume.

NOTES

1. Keeley (1996) cannot accurately correct for varying carrying capacities in these estimates in such a way that he could convert equivalent population densities into possibly very different "population pressures." In those limited cases where such corrections were possible, he considers the data to show either a complex, or weak, relationship between population "pressure" and intensity of conflict (119).
2. This equation by itself can be considered a model for harvesting; in that case, the WN term represents how many people can be "harvested" by war. This model has the interesting property, illustrated by Mooney and Swift (1999, 274–277), that increasing values for W increase the total numbers of casualties up to a point, but when values of N become sufficiently depressed, then further increases in W cause the total number of casualties to decrease (since the achieved population growth will be small because of the small N).

3. In method 3, we first determine the proportion of the study area covered by block survey and the momentary household density of small sites in this surveyed area. Then, we multiply the small-site momentary household density in the surveyed areas by the inverse of the sampling fraction to get total momentary household estimates for small sites. We then add the total momentary households in the community centers (for which we believe we have a census, not a sample) to the estimates for small sites to estimate the total momentary households in the study area. Then, we convert total momentary households into estimates of the momentary total persons who resided in the study area during each period by multiplying the total momentary household figure for each period by six.
4. This results in a view of the frequency of warfare in this region that is generally, but imperfectly, correlated with other measures such as instances of cultural modification and disarticulation of human bone (e.g., Kuckelman, Lightfoot, and Martin 2000) or burned structures and unburied bodies (e.g., LeBlanc 1999). Our measure does not separate raiding and feuding from village-level conflict as was attempted by Lekson (2002). Discovering why there are some differences in our views of warfare frequency depending on which measure we choose is a fruitful area for future investigation.
5. In Matlab, see "help fminsearch," "help ode45," and "help optimset." Initially, one defines the function optimset that creates an optimization options structure `OPTIONS` in which a , b , and c are the default parameters. Next we create a function $f = \text{ODE45}(N, W)$ that solves the system of differential equations [1,3]. Finally, the `fminsearch (@f, (Ndata, Wdata), OPTIONS)` returns optimal parameters a , b , and c that bring the functional J closest to zero. For further details, see Lagarias et al. (1998).

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An Ecological Model for the Emergence of Institutionalized Social Hierarchies on California's Northern Channel Islands

*Douglas J. Kennett, Bruce Winterhalder, Jacob Bartruff,
and Jon M. Erlandson*

ONE OF THE central questions in anthropological archaeology is how and why institutionalized social hierarchies evident in ranked societies and chiefdoms developed independently in multiple locations around the world during the Holocene (Feinman and Manzanilla 2000; Flannery 1998). Status competition and social inequality exist in all human groups, regardless of size or mode of production (Fried 1967; Boehm 2000; Diehl 2000). However, archaeological evidence for significant and institutionalized intragroup differences in status and wealth are confined to the last 13,000 years, well after the first evidence for anatomically modern humans in Africa (ca. 150,000 years ago) and their subsequent appearance throughout much of the Old and New Worlds (Klein 2004). The preponderance of archaeological evidence suggests that for the majority of human history groups remained small, occupied relatively large territories at low densities, and moved periodically to adapt to spatial and temporal fluctuations in resources. The record also indicates that group fissioning, environmental infilling, and emigration to diverse habitats were generally favored

over localized increases in group size and density or other forms of intensification. Under these conditions, institutionalized hereditary leadership and significant differences in status and wealth rarely emerged or persisted.

Archaeological evidence for ranked societies is often found in conjunction with clear indications of localized population aggregation, economic intensification, and territorial circumscription (Blake and Clark 1999; Carneiro 1970; Clark and Blake 1994; Hayden 1981). In some instances, ranking follows heightened commitment to agriculture (Price and Gebauer 1995), but similar developments occurred among hunter-gatherers in areas where wild resources are concentrated, such as in marine and other aquatic habitats (Erlandson 2001; Kennett 2005; Pálsson 1988; Yesner 1980). In these contexts, certain group members were able to acquire greater wealth and status by (1) manipulating economic, social, and political relationships to their own benefit (Earle 1987); (2) controlling the flow of exotic goods used to signal status (Flannery 1972); (3) monopolizing the labor of other group members (Earle 1987; Arnold 2001); and (4) creating ideologies

that justified the uneven distribution of wealth and power (Earle 1987, 1997). The fundamental paradox in such developments is why a majority of group members would cooperate with individuals who ultimately wanted to subordinate and exploit them (Boone 1992).

In this chapter, we develop a multivariate model for the emergence of institutionalized social hierarchies using the broad framework of human behavioral ecology (HBE; Winterhalder and Smith 1992, 2000; Winterhalder and Kennett 2006) and a case study from California's Northern Channel Islands.

AN ECOLOGICAL MODEL FOR THE EMERGENCE OF INSTITUTIONALIZED SOCIAL HIERARCHIES

The origin of institutionalized social hierarchies in ranked societies presents an interesting evolutionary question. HBE generally assumes that decision-making mechanisms are designed by natural selection to lead to fitness-maximizing choices on the part of individuals. In societies with institutionalized social hierarchies, a small number of people receive more than their share of tangible social, political, and economic advantages at the expense of others in the group who are relatively disadvantaged. Temporary, localized discrepancies in status and wealth might arise from shifting relative advantage in the context of individual and lineage-based competition. Societal agreements to establish these advantages in institutions of inequality are the problem. It is relatively easy to understand how positions of power in a group result from individuals pursuing their own self-interests (Clark and Blake 1994). Why group members would cooperate with people who want to subordinate and exploit them is more difficult to comprehend from an evolutionary perspective.

The foundations of institutionalized social hierarchies are competition-based domination and submission behaviors that are evident in all human groups, including egalitarian foragers (Boehm 2000; Diehl 2000). These behaviors are shared by the African great apes, a pattern that

strongly suggests that they were present in a common ancestor (Boehm 2000). As is true with our closest living ancestors (Wrangham 1987; Wrangham and Peterson 1996), these behaviors are most evident in males but are also present, perhaps with different outward manifestations, in females (Boehm 2000). In addition to sex- and age-based social hierarchies, positions of dominance in small-scale egalitarian societies can result from varied hunting prowess or leadership/decision-making qualities (Hawkes 1991). Inherited status or the historical prominence of a lineage can also influence dominance (Diehl 2000), but by definition, prominent social positions in egalitarian societies are not based solely or even primarily on such criteria.

Positions of dominance in a group are not simply a product of hunting prowess or leadership qualities; they depend on the social networks supporting these individuals. Small-scale societies often are composed of subgroup coalitions of hierarchically organized males and females. The cohesion of these groups is fluid and depends on degree of kin relatedness and socioeconomic relationships negotiated among individuals with differing reproductive, social and political agendas. Unequal distributions of resources may be tolerated by closely related individuals, but more distant relatives generally require more tangible incentives to remain loyal. These individual social relationships may provide a means of distributing resources more evenly within a group, but they also can create a form of social debt susceptible to being appropriated by dominant members at critical times. Conversely, the fluid composition of competing coalitions can also serve to suppress domination by one group member (Boehm 2000, 32), a practice evident in many egalitarian societies (Boehm 1993, 2000; Diehl 2000; Erdal and Whiten 1994).

Reproductive skew models provide a framework for tracking the social aspects of group formation and fissure (Summers 2005). They consider the complex relationships between dominant and subordinate members in terms of yield to effort within the group and similar opportunities available through emigration

to a new habitat, in short, through the social realities of group formation. Competition for resources (economic and reproductive) ultimately results in intragroup hierarchies composed of dominant and subordinate members. Dominants emerge through monopolization of economic opportunities, as argued by Boone (1992); subordinate members, by definition, have fewer reproductive and economic opportunities locally and must weigh the costs and benefits of remaining in the group or moving into an adjacent habitat, on their own or as members of other groups. Under these conditions a series of transactions occur between members of the group. Dominant members forcibly eject subordinates, allow them to remain with the group, or may provide economic or reproductive incentives to retain their membership, for various purposes (e.g., economic or defensive). In the same way, subordinates may restrain themselves from claiming their full reproductive or economic share to avoid conflict or eviction from the group.

The most realistic models see these transactions as a tug of war between group members that have limited but differential control over the reproductive and economic resources of the group. If groups are highly circumscribed socially or environmentally (ecological constraints are high), subordinates are more likely to stay with the group even if they are disadvantaged economically or reproductively. The staying incentive for subordinates is proportional to these ecological constraints and dominant members of the group are expected to distribute resources at the minimum level necessary to retain subordinate members.

How might this play out in practice? Archaeological evidence for institutionalized social inequality often parallels evidence for localized increases in group size. Population increase at the local level, due to immigration, inherent growth, or environmental change (e.g., sea level rise), invariably stimulates competition and differential access to resources. Given the fitness maximizing assumption of HBE, the first-order prediction is that the oldest and largest

lineages at any location control the most productive resource patches (e.g., agricultural lands or oak groves). Control of such resources can also result from usurpation due to realignment of competitive factions of subordinate group members. Regardless, competition for localized and limited resources will result in differential access to the best resource patches within a habitat or territory. As access to resources diminishes for some group members, increasingly disenfranchised individuals appraise the costs and benefits of local group membership relative to alternatives as emigrants.

The ideal free distribution (IFD), a model drawn from population ecology (Sutherland 1996), provides a useful framework for considering the changing set of ecological circumstances within which individual decision making takes place. In this model, settlement locations or habitats are ranked by their suitability, a quality measure related to the overall productivity of the resource habitat and, by extension, the fitness of the initial occupants (see Shennan 2007; Winterhalder and Kennett 2006). Habitat suitability is density-dependent; it declines with increasing population density due to exploitation. The model predicts that colonizing people will locate first in the best habitats available (figure 20.1A). As population grows, suitability in this habitat drops due to density-dependent resource depletion or interference arising from competition. When density-sensitive suitability is diminished to a level equal to that of the second-ranked resource patch, further population growth will be divided between them. Individuals relocate to their advantage, reaching an equilibrium distribution of population over habitats when the suitability of marginal habitats is the same. When this is the case, no individual has an ecological or economic incentive to relocate.

An important variant of this model allows for an Allee effect, in which initial increases in the population cause habitat suitability to improve, as a founding group is able to take advantages of economies of scale (figure 20.1B; see Kennett, Anderson, and Winterhalder 2006). Sociality and communication, a highly developed

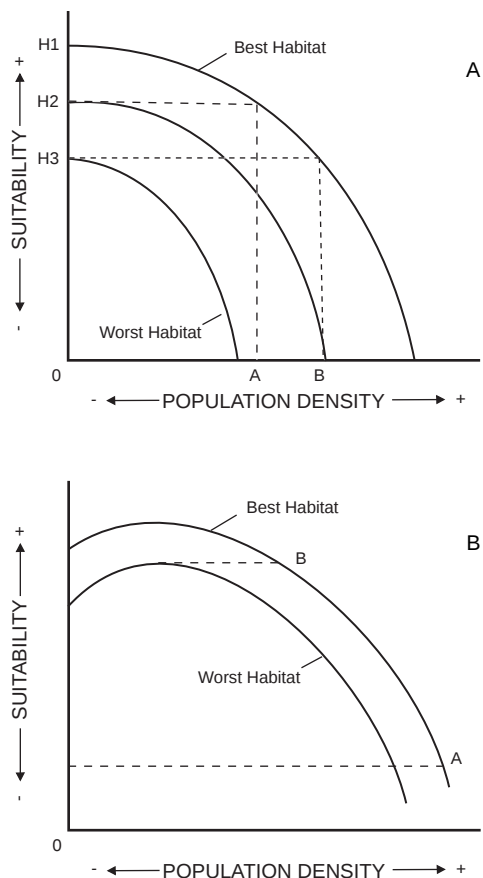


FIGURE 20.1 A, the ideal free distribution 5; B, Allee's principle (after Fretwell and Lucas 1970, 24; Sutherland 1996).

division of labor, and an ability to implement group-dependent technologies such as weirs or irrigation systems suggest that Allee effects will be common in human settlement.

The ideal despotic distribution (IDD) is a variant of the IFD. It allows for individuals with different competitive abilities, highlighting competition and the possibility of differential access to resources within and among groups. If interference arises among competitors of unequal abilities, or if by establishing territories superior competitors or competing groups can protect themselves from density-dependent habitat deterioration by defending better resource opportunities, then the inferior competitors and those without territories are pushed to poorer habitats. Compared to the IFD, a despotic distribution will equilibrate with disproportion-

ate numbers or densities in the lower-ranked habitats. This makes intuitive sense: by garnering disproportionate resources in the best habitats, the better competitors push inferior ones more rapidly into habitats of lesser suitability. In many empirical studies, the IFD serves as a null hypothesis, against which one can measure the effects of interference competition and unequal resource access (Sutherland 1996).

Whatever form they take, the IFD and IDD models show how an incremental quantitative change in one variable (e.g., population size) results in other testable quantitative and qualitative behavioral predictions (e.g., expansion of populations into increasingly less suitable habitats). As with most HBE models, there are few limits on what kinds of variables one might accommodate in using the IFD to generate hypotheses. For instance, climate change might shift the relative suitability (vertical position, thus relative ranking) of the curves. Habitats or subsistence practices highly susceptible to density-dependent degradation will have steep downward slopes; those that generally are not so sensitive to population density will have more shallow slopes. Economies of scale in subsistence or related practices may cause the slope of the curve to be positive through some part of their range.

The decision by an individual or subgroup to leave or fission from their parent community depends on the risks of staying, costs of moving, the likely success of relocating, and the relative advantages of their alternative settlement location. Relative advantage is dependent on the availability and suitability of adjacent habitats and the behavior of other groups in the area. Localized population increase, from endogenous growth or in-migration, followed by community fission results in environmental infilling and the occupation of increasingly marginal zones (environmental packing; Binford 1968, 1983). Localized decreases in habitat suitability due to depletion or interference will precipitate group fission and emigration until most habitable areas are occupied. People may live in large groups, even under severely disadvantaged conditions, if they are circumscribed environmentally,

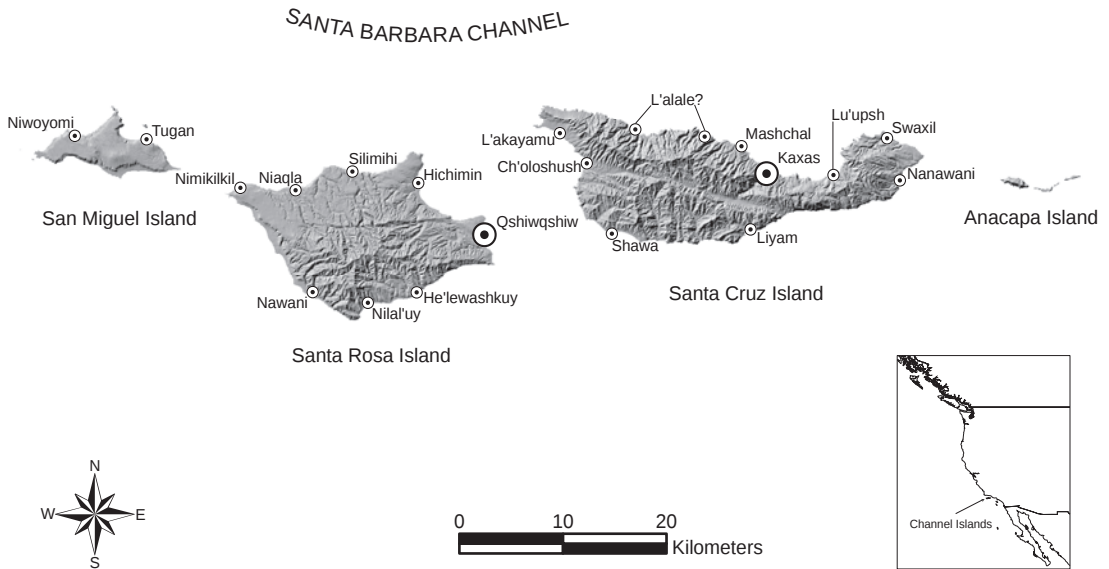


FIGURE 20.2 Map of the California's Northern Channel Islands showing known historic Chumash communities (see Kennett 2005 for details).

demographically, or socially (Carneiro 1970, 1978). Circumscription includes social boundaries maintained by the threat of violence from adjacent communities, real or perceived. Socialization for fear of others is a common form of coercion used to manipulate subordinate members of a group (Kantner 1999; Lekson 2002), and it can be used to reduce the attractiveness of settlement locations. Subordination to members of a group may be the best alternative. Ideological manipulation can also play an important role in the perception of the costs and benefits of staying with the group, while being subjugated and exploited by others (Earle 1987).

A CASE STUDY FROM CALIFORNIA'S NORTHERN CHANNEL ISLANDS

As a first test of this general model, we turn to the Late Holocene archaeological and ethnohistoric records on California's Northern Channel Islands (figure 20.2). Erlandson (1997) and Erlandson and Rick (2002) have argued that population growth, technological innovations, and intensification during the Early and Middle Holocene set the stage for the development of cultural complex-

ity during the Late Holocene in the Santa Barbara Channel region. They believe that technological and other cultural changes in the area generally accelerated through time, especially after about three thousand to four thousand years ago when, they argue, local populations reached a state of territorial circumscription. A variety of data also suggest that the Island Chumash and their ancestors had significant impacts on nearshore marine ecosystems during the Early and Middle Holocene (Erlandson et al. 2005; Kennett 2005; Rick, Kennett, and Erlandson 2005; Walker et al. 2002), leading to measures (intensification, extensification, resource switching, etc.) designed to maintain or increase the yields of local fisheries.

An estimated three thousand people lived on the Northern Channel Islands at historic contact (1542 CE), occupying at least twenty-two villages varying in size and sociopolitical importance (Johnson 1982, 1993; Kennett 2005). The locations of many of these villages were described by Chumash informants (Johnson 1982), and archaeological work substantiates their existence (Arnold 1990; Johnson 1993; Kennett 2005; Kennett et al. 2000; Kroeber 1925). Ethnohistoric records suggest that the

Island Chumash were organized primarily at the village level—economically and politically—and that some of these communities were governed by hereditary leaders or chiefs (Johnson 2000; Kennett 2005).

A more limited number of ethnohistoric accounts suggest the periodic integration of island communities under one or two influential hereditary chiefs (Johnson 1988, 2000). On the northeastern end of Santa Cruz Island at Prisoner's Harbor, the village of Kaxas was well positioned to be an important economic center, a natural port of trade between the islands and the mainland. The village of Qshiwqshiw, situated at the mouth of Old Ranch Canyon on Santa Rosa, was also a natural geographic center for the outer islands (Johnson 1993). Mission records suggest that Kaxas was the second-largest village on Santa Cruz and an important economic and political center (Johnson 1982, 1993). Historically, at least one chief lived in this village. Likewise, baptismal records suggest that Qshiwqshiw was one of the larger communities on the outer islands of Santa Rosa and San Miguel and that it had at least four chiefs in residence historically (Johnson 1993). It was also an important center for manufacturing plank canoes (Brown 1967, 16)—watercraft with great economic, social, and political value (Arnold 1995).

When and how ascribed status or institutionalized social hierarchies evident at historic contact first emerged on the islands is open to debate. The evolutionary scenarios put forward emphasize gradual or punctuated mechanisms to varying degrees (Arnold 1987, 2001; Erlandson and Rick 2002; Kennett and Kennett 2000; Kennett 2005; King 1990; Martz 1984; Raab and Larson 1997). At issue are some of the most basic facts, as well as causal mechanisms. We offer the environmental, demographic, and sociopolitical predictions of the IFD/IDD model as a framework to explore potential causal mechanisms and the existing archaeological data with the idea of establishing predictions to be tested with future work.

As a starting point, we employ a Geographic Information System (GIS) to rank the suitability

of potential coastal village locations on the Northern Channel Islands based on environmental variables that we argue to be good indicators of habitat suitability. The variables include watershed size, coastline type, and kelp forest distribution. We then compare the character of Late Holocene demographic expansion against the ranked suitability of these habitats as a first test of the IFD/IDD model. Of the various possible hypotheses, we provide a qualitative test of two predictions: (1) habitats will be initially occupied in descending rank order of their measured suitability; and (2) social stratification will be coincident with saturation of viable habitat locations, indicative of heavy exploitation and steep declines in suitability across all occupied areas. Saturation of all but the lowest-ranked habitats will parallel the emergence of institutionalized social hierarchies.

NORTHERN CHANNEL ISLANDS GIS

All of the archaeological and environmental coverages were created using ESRI's ArcMap and integrated with existing geographic data sets for the Northern Channel Islands (see Kennett 1998, 2005). Primary village locations were identified as sites clearly occupied for extended periods of time, serving as central places for a variety of economic and social activities. We estimate the environmental suitability of forty-six potential village locations contingent on (1) area of watershed; (2) length of adjacent coastline, in three categories—cliffs, sandy beaches, and rocky intertidal; and (3) area of nearby offshore kelp forest habitat. Examples of high- and low-ranked village locations are shown in figure 20.3; we explain and justify these suitability measures below.

WATERSHED SIZE One of the essential and more restricted resources on these islands, particularly on the smaller islands of Anacapa and San Miguel, is drinking water (Kennett 2005). In the absence of instrumental records for the flow of island streams, we use watershed size as a proxy for the availability of fresh water at each of the forty-six drainage mouths. Watersheds on

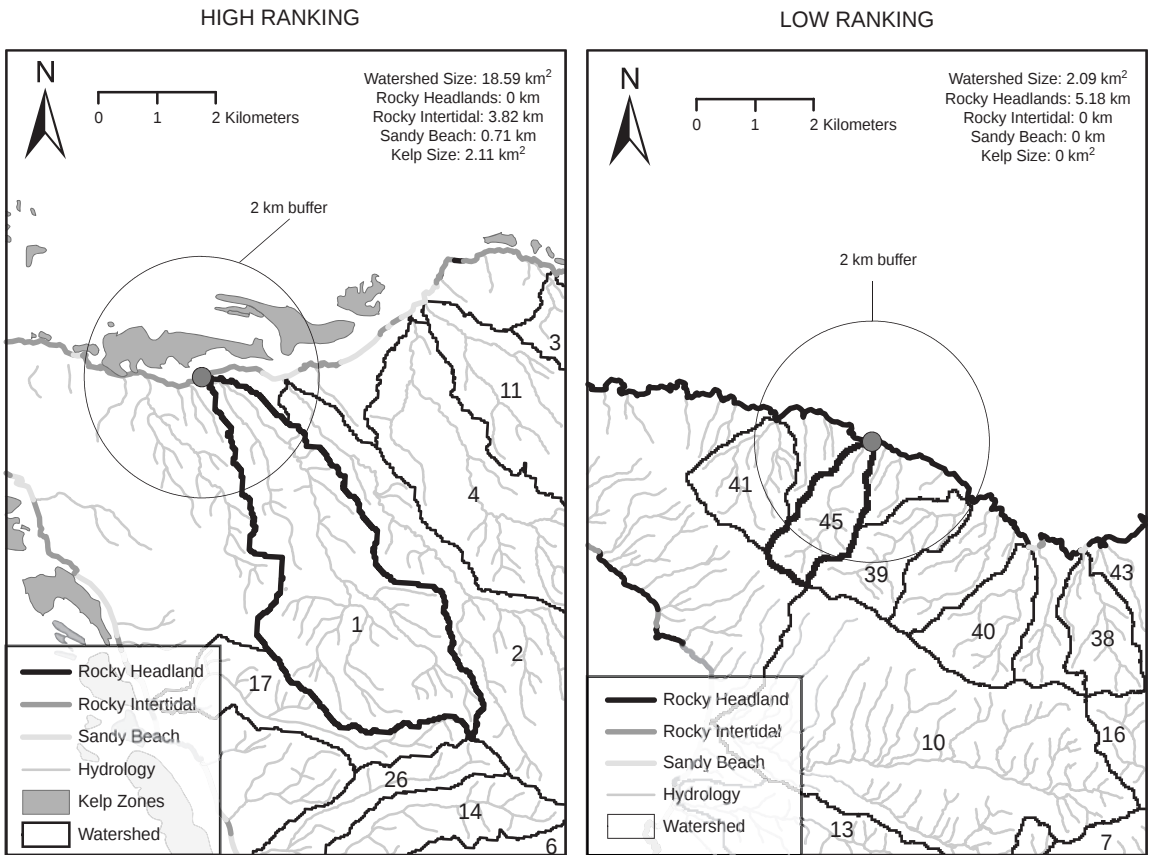


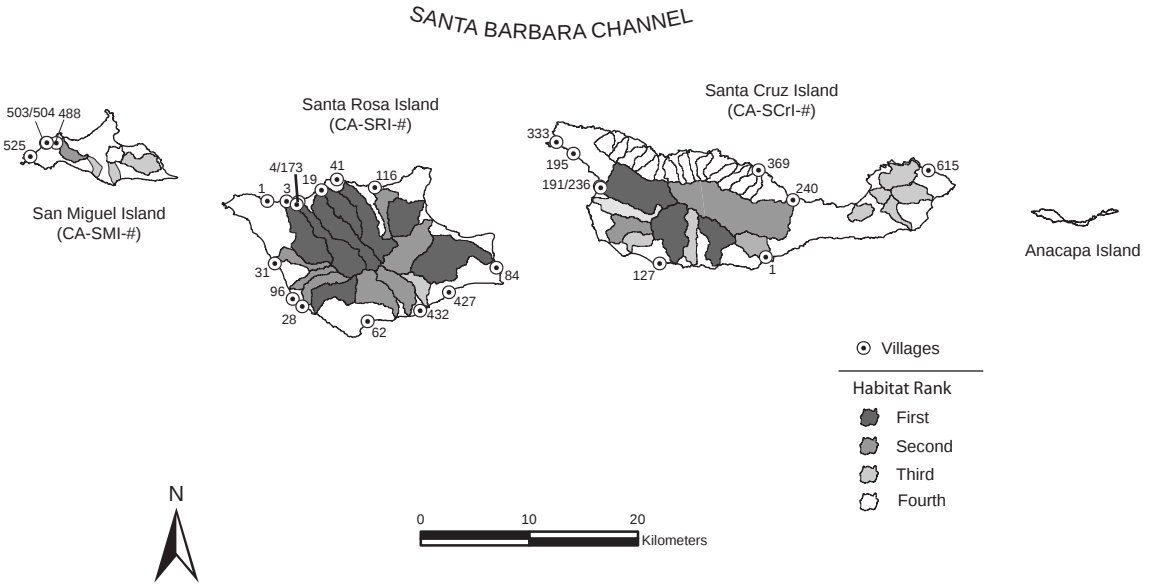
FIGURE 20.3 Examples of first- (good) and fourth- (bad) ranked village locations on the Northern Channel Islands.

the islands were defined using ArcMap, a digital elevation model for these islands (DEM, 30 meters), and ESRI's grid function for hydrological analysis. The character and extent of watersheds was then verified using color digital aerial photographs (1.5-meter resolution; see Kennett 1998). Drainage size is more heavily weighted (50 percent) in our overall assessment of suitability than other features, based on the importance of drinking water and the added value and importance of terrestrial plant foods and trees—relatively limited resources in these insular environments.

SHORELINE TYPE The shoreline surrounding each of the Northern Channel Islands consists of rocky sea cliffs, sandy beaches, and rocky intertidal habitats.¹ Rocky sea cliffs are relatively inaccessible and had limited economic value for prehistoric inhabitants of these islands.

They only figure into our measure of suitability by reducing the extent of sandy beach and rocky intertidal habitats within two kilometers of the mouths of the forty-six potential village locations. We consider the succession of rocky intertidal habitats (upper, middle, and lower) and the associated tide pools to have greatest economic potential due to the broad range of easily collected marine organisms that occupy them (see de Boer et al. 2002; Kennett 2005; Schoenherr, Feldmeth, and Emerson 1999). We assign this feature a 30 percent contribution to overall suitability. A digital map of these shoreline types was created using a combination of coastal surveys and aerial photography, and the length of each shoreline type was recorded within a two-kilometer stretch on each side of the mouth of each of the forty-six ranked drainages.

A



B

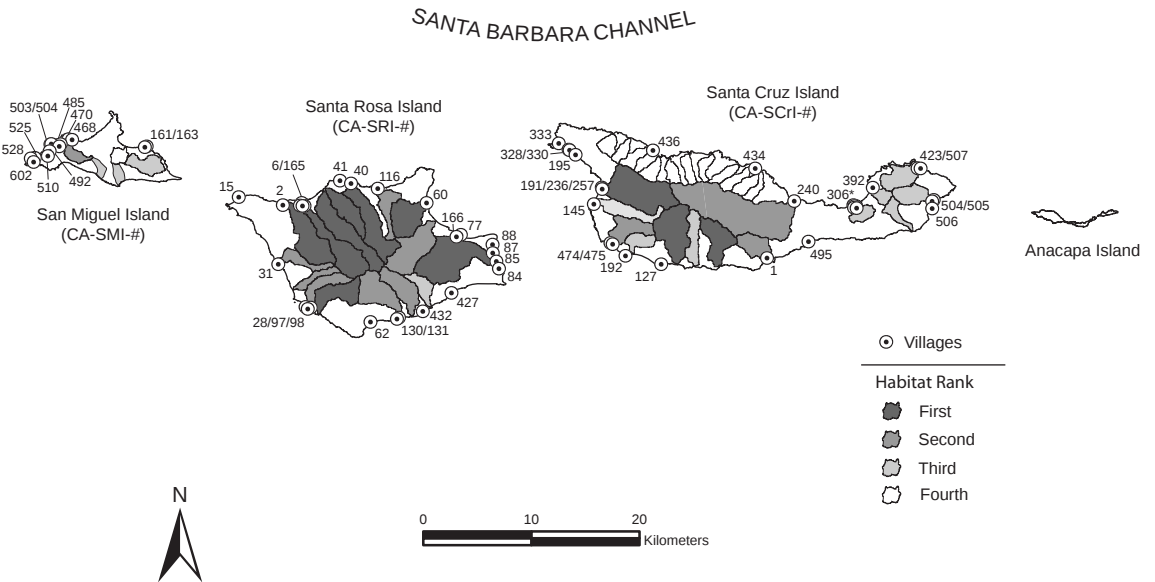


FIGURE 20.4 Geographic distribution of first-, second-, third-, and fourth-ranked village locations compared with known settlements dating to between (A) 3,000 and 1,500 BP and (B) 1,500 and 250 BP.

KELP FORESTS Patches of giant (*Macrocystis pyrifera*) and bull (*Nereocystis* spp.) kelp forests fringe each of the Northern Channel Islands, providing a three-dimensional habitat that supports a wide range of marine organisms

(Kinlan, Graham, and Erlandson 2005). The distribution of kelp is dependent on favored rocky reef substrates in shallow water habitats (<25–28 meters) and, depending on the character and depth of the substrate, can be restricted to

nearshore or extend well offshore (Engle 1993). This marine plant grows quickly to great lengths (60 meters) and creates a dense canopy on the water surface that provides food and shelter for fishes, invertebrates, and sea mammals (e.g., sea otters—*Enhydra lutris*—and harbor seals—*Phoca vitulina*; Schoenherr et al. 1999, 101). We estimated the lateral extent of kelp based on forest surveys (1980–1988 and summer of 1989), by combining color digital aerial photographs showing kelp canopy (1.5 meters), with the 25-meter isobath surrounding each of the islands thought to be a good predictor of the maximum aerial extent of kelp forests (Kinlan et al. 2005, 134). The contribution of kelp forest area to overall suitability of coastal village locations, based on its lateral extent within a two-kilometer radius of each drainage mouth, was estimated at 20 percent.

These environmental quality proxies are listed in table 20.1 along with the weighted overall suitability measure for each potential village location. The spatial distribution of first- (1–11), second, (12–22), third- (23–34), and fourth- (35–46) ranked village locations are shown as watershed outlines in figure 20.4. It is not surprising that the larger islands of Santa Rosa and Santa Cruz have a high number of first- and second-ranked village locations, given the larger size of their drainages, many of which provide a perennial source of drinking water and a greater diversity of edible or utilitarian plants and trees. Of these two islands, Santa Rosa has the largest number of first-ranked village locations. A majority of these occur on its northern side, but first- and second-ranked locations also occur along the southern and eastern coasts. The high concentration of first- and second-ranked village locations on Santa Rosa is a product of big watersheds, long stretches of rocky intertidal habitat, and laterally extensive, offshore kelp forests. First- and second-ranked village locations on Santa Cruz occur on the southern and western coasts, except for a second-ranked village location on its northern side at Prisoner's Harbor (see CA-SCrI-240). The highest-ranked (second-tier) village location on

the smaller island of San Miguel occurs on its northwestern side, with the remaining village locations of third and fourth rank. Third-ranked village locations also occur on the eastern end of Santa Cruz, and the highest concentration of fourth-ranked locations occurs along the northern coast, a product of small drainage size and the predominance of inaccessible coastal sea cliffs along with a lack of substantial kelp forests.

DEMOGRAPHIC EXPANSION AND THE EMERGENCE OF INSTITUTIONALIZED SOCIAL HIERARCHIES

The IFD model predicts that the highest-ranked habitats will be occupied first and most persistently through time, with secondary and tertiary habitats settled later in time, and perhaps also with lesser permanence. The despotic variant of the model (IDD) predicts that as local competition increases and certain individuals hoard access to resources, other individuals will opt out of the group and settle secondary and tertiary locations as long as the benefits of doing so outweigh those of remaining in the parental group. Of course, the benefits of staying in a group, even with greater subjugation, increase as secondary and tertiary habitats become saturated. It is under these environmental and social conditions that we predict the first evidence for institutionalized social hierarchies. We limit our analysis here to villages dating to the Late Holocene (3,000–200 BP), breaking them into two periods: those dating to between 3,000 and 1,500 BP (figure 20.4A) and to sites dating to between 1,500 and 200 BP (figure 20.4B).

The distribution of settlements between 3,000 and 1,500 BP is a continuation of demographic trends evident on the Northern Channel Islands during the Middle Holocene (7,500–3,000 BP; Kennett 2005). The largest villages were located on the north coast of Santa Rosa in the region of the highest-ranked habitats. Most of the Middle Holocene village complexes on northern Santa Rosa (CA-SRI-1, 3, 4 at the mouth of Arlington Canyon and CA-SRI-41

TABLE 20.1. *Environmental Parameters Used to Rank Coastal Village Locations*

DRAINAGE NAME	DRAINAGE SIZE		ROCKY INTERTIDAL		SANDY BEACH		ROCKY HEADLANDS		KELP BED DENSITY		WEIGHTED SCORE	
	KM ²	RANK	KM	RANK	KM	RANK	KM	RANK	KM ²	RANK	SCORE	RANK
Cañada Tecolote	12.14	7	3.82	3	0.71	36	0.00	40	1.70	3	6.65	1
Arlington Canyon	11.93	8	2.87	6	1.54	29	0.00	40	1.46	8	8.45	2
Cañada Soledad	12.28	6	2.57	14	1.95	17	0.21	36	0.67	14	10.15	4
Water Canyon	12.28	5	0.57	33	2.55	8	1.21	22	0.95	13	14.75	12
Ranch Canyon	8.84	11	2.58	13	1.90	19	0.00	40	1.38	10	11.85	5
Old Ranch Canyon	18.59	2	1.46	26	2.98	6	0.00	40	0.12	26	13	8
Unnamed (China Camp 1)	7.36	14	2.73	10	2.10	16	0.00	40	1.13	11	12.45	6
Cañada Christi	18.10	3	1.57	24	2.46	12	0.94	24	0.11	27	13.35	10
Cañada Verde	11.83	9	4.30	1	0.30	39	0.56	28	0.43	20	9.75	3
Laguna Canyon	12.55	4	2.37	16	1.58	27	0.80	26	0.04	30	12.65	7
Dry Canyon	6.84	15	2.66	11	1.95	17	0.21	36	0.55	18	14.35	11
Willows Canyon	7.97	12	2.83	7	1.77	20	0.14	38	0.06	28	13.3	9
Unnamed (Bee Rock)	3.79	25	1.95	17	2.49	10	0.00	40	1.86	1	18.25	17
Jolla Vieja Canyon	9.31	10	1.18	28	1.43	30	1.84	18	0.58	17	17.45	15
Unnamed (China Camp 2)	4.83	22	2.56	15	2.47	11	0.00	40	1.44	9	17.4	14
Cañada de los Sauces	6.20	17	2.74	9	2.44	13	0.21	35	0.25	23	15.3	13
Cañada de la Calera (1)	34.35	1	0.00	37	1.70	24	3.00	14	0.03	35	18.05	16
Pozo Canyon	6.45	16	1.10	31	3.27	2	0.29	34	0.42	21	20.55	23
Wreck Canyon	7.44	13	1.14	30	1.36	31	2.21	16	0.61	16	19.45	19
Unnamed (Cluster Point)	2.81	28	1.34	27	3.17	3	0.00	40	1.77	2	22.55	26
Otter Creek	2.61	34	3.88	2	1.70	25	0.00	40	1.47	7	19.9	21

Cañada Lobos	4.74	23	2.66	12	0.30	39	1.90	17	0.31	22	20.35	22
San Augustine Canyon	3.62	26	1.68	20	1.72	23	1.48	19	0.43	19	23	27
Smugglers' Canyon	5.13	20	1.89	18	1.76	21	1.29	21	0.03	34	21.55	24
Montañon Canyon	2.78	30	1.17	29	2.35	15	0.89	25	0.98	12	26.25	28
Coches Prietos Canyon	5.39	19	3.11	5	0.92	33	1.45	20	0.00	43	19.1	18
Johnsons Canyon	3.32	27	0.59	32	3.74	1	0.11	39	0.14	25	26.9	29
Alamos Canyon	5.08	21	3.21	4	0.90	34	0.80	26	0.00	43	19.85	20
Willow Canyon	4.63	24	2.82	8	1.68	26	0.32	29	0.00	43	22.15	25
Unnamed (San Miguel South 2)	1.53	45	1.63	22	3.03	4	0.31	33	1.57	6	30.2	31
Scorpion Canyon	6.17	18	0.00	37	0.16	43	5.51	9	0.01	37	27.8	30
Unnamed (China Harbor)	2.63	33	0.00	37	1.76	22	2.69	15	0.17	24	32.3	33
Unnamed (San Miguel South 1)	1.28	46	1.65	21	2.50	9	0.31	30	0.65	15	32	32
Valdez Canyon	2.65	32	0.22	34	0.39	38	5.65	8	0.03	32	32.9	34
Unnamed (Twin Harbors 1)	2.81	29	0.00	37	0.00	44	6.63	1	0.01	39	33.65	35
Nidever Canyon	1.97	44	1.54	25	2.41	14	1.13	23	0.06	29	34.55	36
Orizaba Canyon	2.73	31	0.00	37	0.00	44	6.27	3	0.01	39	34.65	37
Unnamed (Lady's Harbor)	2.36	37	0.00	37	0.87	35	5.31	10	0.03	31	36	38
Unnamed (Trident Cove)	2.21	39	0.22	34	0.70	37	5.73	6	0.03	32	36.35	40
Hazard's Canyon	2.58	35	0.22	34	0.20	42	5.29	11	0.00	43	36.25	39
Unnamed (Dick's Cove)	2.30	38	0.00	37	0.28	41	6.25	4	0.01	39	38	42
Unnamed (Profile Point)	2.55	36	0.00	37	0.00	44	5.66	7	0.00	43	37.75	41
Diablo Canyon	2.09	41	0.00	37	0.94	32	5.85	5	0.01	38	38.9	43
Cañada de la Calera (2)	1.99	43	0.00	37	1.57	28	3.89	13	0.02	36	39.4	44
Unnamed (Twin Harbors 2)	2.04	42	0.00	37	0.00	44	6.57	2	0.01	39	40.15	46
Unnamed (Ruby Rock)	2.09	40	0.00	37	0.00	44	5.18	12	0.00	43	39.75	45

at the mouth of Cañada Verde) continued to be occupied between 3,000 and 1,500 BP. This is also the case at one known village on western Santa Cruz Island (CA-SCrI-333; Wilcoxon 1993; King 1990), a community not positioned directly on one of our ranked village locations, but within the vicinity of the highest-ranked settlement location on that island. Continued use of cemeteries at all of these villages between 3,000 and 1,500 BP indicates a certain degree of settlement continuity at these locations (Kennett 2005; King 1990).

However, it is between 3,000 and 1,500 BP that settlements expanded to many of the other first and second ranked habitats along the coasts of Santa Rosa and Santa Cruz. Likewise, the first definitive evidence for a settled village occurs toward the west end of San Miguel within or near the highest-ranked village location on that island (SMI-488, 503/504). There are also several village sites in unranked locations (CA-SRI-525, SCrI-195, 333). All of these sites are within the vicinity of high-ranked habitats and may be seasonal residences established to exploit specific, nearby resources not accounted for in our model. This is likely the case with CA-SMI-525, a site located near one of the largest breeding colonies of sea mammals on the western coast of North America (Walker et al. 2002). Despite these exceptions, the available archaeological evidence suggests that many second- and third-ranked village locations were not occupied between 3,000 and 1,500 BP, and island-wide population levels appear to be well below what would saturate viable habitats. This of course implies quite slow cumulative population growth through the early portions of the archaeological sequence, something not yet well explained.

By about 1,500–1,300 BP, primary villages were distributed around the perimeters of Santa Rosa and Santa Cruz, and along the north coast of San Miguel (Munns and Arnold 2002; Glassow 1993; Kennett 1998; Kennett and Conlee 2002; figure 20.4B). Many of the first-, second-, and third-tier habitats were occupied by this interval. There appears to be a change in the character and structure of primary villages after

this time that suggests even greater settlement stability. These changes are difficult to quantify because the large-scale excavations needed to better characterize them are sorely lacking. However, primary villages occupied during the latest Holocene (after 1,500–1,300 BP) are generally located on promontories or cliff faces close to springs or near the mouths of perennial streams. Compared with primary village sites dating to between 3,000 and 1,500 BP, these villages tend to be more compact and not as laterally extensive (Kennett 1998).

Evidence for relative stability after this time includes more substantial domestic features, larger and deeper midden deposits, and greater faunal and artifact diversity (see Kennett 2005; Rick 2004). The consolidation of primary villages after about 1,500–1,300 BP also corresponds to some notable changes in the location and structure of cemeteries (King 1990). These newly established cemeteries were often used continuously into the Historic period; supporting data suggest settlement continuity at certain locations between 1,300 and 200 BP. Demographic expansion parallels evidence for decreases in body size in both men and women and evidence for poor health, as indicated by increasing incidences of cribra orbitalia and periosteal lesions in skeletal material through time (Lambert 1994, 1997; figure 20.5).

Several lines of evidence support the idea that the institutionalized social hierarchies evident at historic contact were well established on the islands by the beginning of the Late Period (ca. 650 BP; Arnold 2001; Kennett 2005). Varied interpretations of the available mortuary data suggest that ascribed status differences had emerged by at least this time (Arnold 2001; King 1990). Many of the named historic island communities were occupied by the beginning of this interval, suggesting continuity between the Late and Historic periods. Some of these villages are located in more marginal fourth-tier locations along the north coast of Santa Cruz Island (e.g., CA-SCrI-434, -436).

Institutionalized social hierarchies certainly developed on the Northern Channel Islands

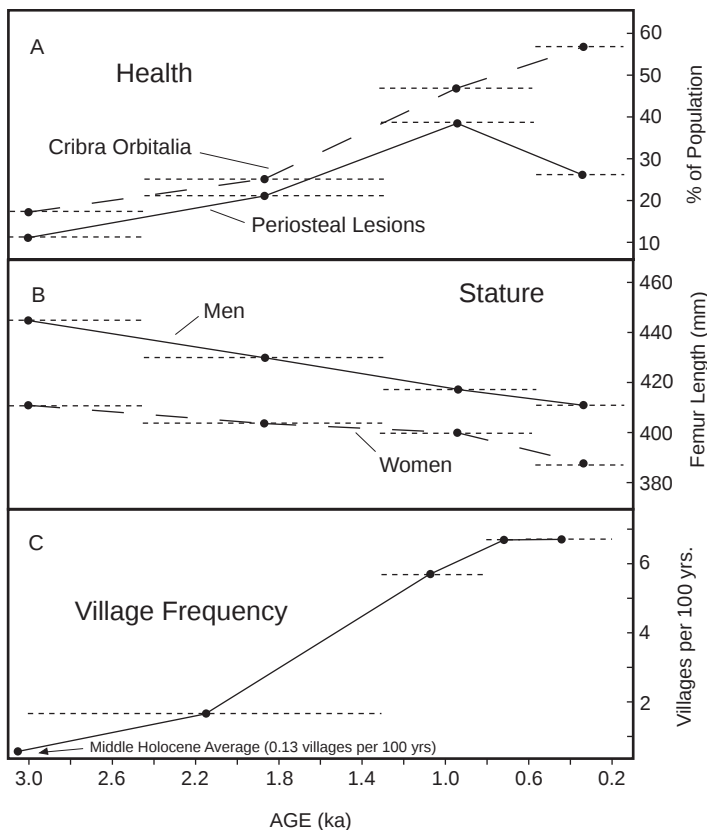


FIGURE 20.5 Demographic trends on the Northern Channel Islands during the last three thousand years. A, Changes in health through time (Lambert 1994); B, changes in body size (stature) through time based on femur length (Lambert 1994); C, number of villages per one hundred years.

prior to 650 BP, but the exact timing is an open question that requires future work. High-status burials in the Santa Barbara Channel region often contain a diverse range of funerary objects, including canoe effigies and plank canoe parts. King (1990) used mortuary data from the Northern Channel Islands to argue for the development of ranked societies and ascribed status by the end of the Early Period (ca. 2,400 BP). The same data have been used more recently to demonstrate that hierarchical social organization developed on these islands later, by about 800 BP (Arnold 2001). In both instances, the raw data needed to evaluate these claims are not presented, and the resolution of this debate awaits a comprehensive analysis of mortuary remains from island contexts, coupled with an ancient DNA study that would allow for the reconstruction of familial relationships and provide the data needed to link wealth and status with heredity.

Although the precise timing for the development of institutionalized social hierarchies on

the Northern Channel Islands is unclear, our IFD/IDD model predicts that this occurred sometime between 1,500 and 650 BP. Most first-, second-, and third-ranked habitats on these islands were occupied by this time. Climatic conditions through this interval were generally dry and unstable with a series of severe droughts (Kennett and Kennett 2000; Kennett 2005; Raab and Larson 1997), periodically reducing the overall suitability of all habitats. Potable drinking water was likely unavailable in all fourth- and some third-ranked habitats for much of this interval. Osteological evidence indicates an increase in lethal violence (Lambert 1994), and this further destabilized the social and political milieu. Violence was further exacerbated by the introduction of the bow and arrow between 1,500 and 1,300 BP (Kennett 2005). It is precisely under these conditions—environmental, demographic, and social circumscription—that the IFD/IDD model predicts corporate group formation, asymmetrical access to material and

reproductive resources, and institutionalized social inequality. Additional work on archaeological sites dating to this interval is required to test this prediction.

CONCLUSIONS

Although there is still much to be learned about settlement and demography on the Northern Channel Islands, our analysis suggest that the IFD and IDD models provide a useful framework for predicting when institutionalized social hierarchies would have been favored during the Late Holocene. The predicted first-tier settlement locations on the northern and eastern coasts of Santa Rosa and the western end of Santa Cruz supported primary village locations established during the Middle Holocene. Second-tier settlement locations (e.g., south coasts of Santa Rosa and north coast of San Miguel) that were used logistically during this time do not appear to have been occupied permanently until after 3,000 BP. Under these ecodeographic conditions—favorable habitats for expansion and limited equilibrium impact on overall suitability of all habitats—social hierarchies would not have been favored. The expansion of primary villages to most second-tier settlement locations during the Late Holocene would have been more favorable for their development, particularly after 1,500–1,300 BP when villages were well distributed around the coast of Santa Rosa and Santa Cruz and along the north coast of San Miguel.

Growing populations, intensified resource use, and declines in equilibrium habitat suitability later in the Holocene (after 1,500 BP) would have stimulated competition within and among communities, creating a situation where individuals would have had differential access to key resources. Given unfavorable climatic conditions, we argue that most or all viable habitats were occupied by between 1,500 and 1,300 BP, all of them experiencing the stress of marginal, density-dependent suitability. Due to the lack of viable, unoccupied habitats on the islands (fourth-tier sites or lower) after this time, people

were more likely to accept lower-quality lifestyles—reduced minimal incentives provided by dominants—compared to others in the community, rather than colonizing the most marginal parts of the islands. Of course, this was a gradual process; as viable settlement locations were saturated, continued population growth would increase pressures for social hierarchies within groups. Once intergroup competition and conflict were present, no group could benefit from restricting its population size, thus increasing its vulnerability.

Population increase and demographic expansion were at the core of the cultural changes evident on the islands between 1,500 and 650 BP. Palaeoclimatic data for the region suggests that this interval was highly unstable climatically and that the already dry conditions that prevailed through this period were interrupted by megadroughts that impacted much of southern California (Stine 1994; Kennett and Kennett 2000). Dry conditions further circumscribed populations, and environmental instability stimulated conflict and competition for access to perennial water sources. Larger and more stable settlements emerged on the islands during this period. It is within this context that social hierarchies were favored, and certain individuals were able to control aspects of the political and economic system for their own benefit. The social ranking and hierarchical political structure likely solidified in island Chumash society under these conditions. More detailed study of mortuary remains will be required to determine the exact antiquity of institutionalized social inequality between 1,500 and 600 BP, but Arnold's (2001) estimate of 800 BP is consistent with the predictions of the IFD/IDD model.

NOTE

1. At least one substantial estuary, and an associated suite of resources, also existed at the mouth of Old Ranch Canyon (Eastern Santa Rosa) during the Middle Holocene. It appears to have been largely in-filled in by the Late Holocene (Rick et al. 2005).

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Population, Sociopolitical Simplification, and Cultural Evolution of Levantine Neolithic Villages

Ian Kuijt

HOW DOES ONE describe and model the tempo and underlying causes of cultural change? This represents one of the central questions for studies of cultural evolution. Any attempt to address it faces two interrelated challenges. First, researchers need to develop interpretive models that incorporate both external and internal causes for the direction and tempo of cultural change. Depending on the case study in question and their specific agendas, researchers (Diamond 2005; Shennan 2000; Tainter 1998) have explored diverse explanations, such as paleoclimatic change, population growth, and ideology, to account for short- and long-term cultural change, but it is uncommon for researchers to develop holistic models that incorporate both internal and external processes. Second, archaeologists need to develop more nuanced models of cultural evolution in which microscale processes are linked to macroscale historical patterns. Microevolutionary studies are now well established in archaeology, while Prentiss and Chatters (2003), inspired by Gould (1989), have proposed a general model for major shifts in cultural

patterns which sees them as a result of short-lived diversification events arising from the emergence of new economic opportunities. These lead to rapid population growth and a process of cultural cladogenesis at a regional scale. Subsequently, the branches are usually rapidly pruned in a process that the authors refer to as “decimation,” through competition, maladaptation, and vulnerability to major environmental change. Nevertheless, stimulating though this macroevolutionary perspective is, it does not as it stands offer fine-grained models of the processes involved.

In this essay, I argue that an understanding of the emergence and disappearance of large-scale cultural macropatterns must be modeled from the perspective of simultaneous internal and external processes, and that the models for these processes need to be generated from the ground up through individual case studies. Focusing on the emergence and abandonment of Levantine Pre-Pottery Neolithic villages, I argue that the initial aggregation of people into villages was a by-product of significantly improved climatic and vegetative conditions over

several thousand years, as well as local scale economic intensification and new systems of food storage. A number of researchers (e.g., Rollefson 1996; Simmons 2000) have suggested that climatic changes, local environmental degradation, and overgrazing, were linked to the subsequent abandonment of Pre-Pottery Neolithic lifeways around 8,500 years ago. It is proposed here that this is not a satisfying answer on its own. While the proximal causes of village abandonment may have been linked to climatic deterioration and overexploitation of areas around villages through grazing, I argue that the process also reflects internal shifts in village social organization (Kuijt 2000) and, more specifically, sociopolitical simplification.

In what follows, I first outline some of the demographic and economic foundations within different phases of the Pre-Pottery Neolithic and employ these to briefly articulate some of the evolutionary foundations for village emergence. This is covered in more detail elsewhere (Kuijt and Goring-Morris 2002). Second, I explore the potential interface between paleoclimatic change during these periods and demographic changes within them, including the appearance and abandonment of large, densely occupied Neolithic villages. Third, I argue that the emergence of Pre-Pottery Neolithic villages was at least partially related to economic intensification of agricultural systems. Finally, I explore how the eventual abandonment of these villages may have been linked to a combination of climatic deterioration, as well as internal factors leading to the simplification of social-political systems.

TEMPOS OF CHANGE IN LATE PRE-POTTERY NEOLITHIC VILLAGES

Archaeologists now know that during the two thousand years of the Levantine Pre-Pottery Neolithic there were remarkable shifts in economic systems, social practices, and nucleation and dispersal of people into and out of early agricultural villages. This represents exactly the kind of large-scale shift in resource management system discussed by Prentiss and Chatters. In

contrast to the smaller camps of the earlier Pre-Pottery Neolithic, many of which may have only been seasonally occupied or utilized, and even the first domesticated villages of the Middle Pre-Pottery Neolithic B (hereafter MPPNB), the Levantine Late Pre-Pottery Neolithic (hereafter LPPNB) settlements were characterized by population nucleation and the development of regional social and economic centers (e.g., Gebel 2004; Rollefson 1987; Rollefson and Köhler-Rollefson 1989; Simmons 2000). These LPPNB nucleated agricultural villages were significantly greater in size, with a higher density of architecture compared to earlier MPPNB settlements. While it is possible that this apparent patterning is linked to low visibility of smaller settlements and the survey methods employed by archaeologists (though regional survey around the multiperiod settlements of 'Ain Ghazal failed to identify peripheral smaller LPPNB hamlets or ancillary sites (Simmons and Kafafi 1988), researchers have generally accepted that the LPPNB was characterized by a settlement system focused on the nucleation of people into villages of unprecedented size, followed by the abandonment of these practices in the PPNC and, more visibly, in the Pottery Neolithic periods (Simmons 2000).

Simmons (2000) outlines a three-stage tentative scenario for the late Pre-Pottery Neolithic trajectory that blends elements of internal and external factors. In his model, the first stage is characterized by population aggregation into large regional centers. He argues, "For whatever reason, be they climatic, ecological overexploitation, or social, the MPPNB and LPPNB witnessed the establishment of major centers in the eastern Levant, such as 'Ain Ghazal, Basta, and Wadi Shu'eib" (221). In the second stage, with the transition to the PPNC, Simmons sees dramatic economic and social changes, with significant shifts in architecture, mortuary practices, and economy. From his perspective, stage 2 was characterized by disharmony, potentially linked to ecological degradation and mismanagement. With the transition to the Pottery Neolithic as stage 3, Simmons sees a cultural response to climatic changes, one in which there were

profound social and economic shifts, specifically the evolution of the twin strategies of pastoralism and farming (225). Simmons's study is by no means the only treatment of this topic, but taken in conjunction with other synthetic work on culture change during the Neolithic (see Kuijt and Goring-Morris 2002; Rollefson 1998), it has made us aware that there was significant variation between various periods of the Pre-Pottery Neolithic.

On the basis of improved knowledge of paleoenvironmental changes, as well as the publication of a number of comparative works (Gebel 2004; Kuijt and Goring-Morris 2002; Goring-Morris and Belfer-Cohen 1998; McCorriston and Hole 1991; Neef 2004), it is now possible to develop a more nuanced understanding of the broader evolutionary sequence of the Pre-Pottery and Pottery Neolithic. This study examines some of the possible relationships between the physical and social conditions of life in early agricultural villages and broader long-term changes, focusing on some of the interrelationships between long-term population growth and gradual, yet important, changes in the living conditions within early agricultural communities. By extension, I want to consider how human communities might have responded to such changes, reflecting on certain aspects of daily life, such as living conditions and the control of subsistence resources.

A BRIEF OUTLINE OF THE RISE AND FALL OF LATE PRE-POTTERY NEOLITHIC VILLAGES

Looking at late Pre-Pottery to early Pottery Neolithic in the southern Levant (the areas comprised of modern-day Jordan, Israel, southern Syria, and eastern Egypt), we can track a trajectory of aggregation of people into terminal LPPNB villages and the founding of new, or expansion of existing, villages. This was followed by the dispersal of Pottery Neolithic people into small hamlets by around 8,000 BP. However, it appears that while some large LPPNB villages were abandoned during the PPNC period, oth-

ers continued to be occupied and maintained during the PPNC and the Pottery Neolithic A period (Gopher and Gophna 1993; figure 21.1).

Population aggregation in the LPPNB co-occurs with the appearance of new architectural and social systems. New architectural systems include the appearance of densely packed residential villages, in some cases with two-story architecture (Banning 1998; Bar-Yosef and Meadow 1995; Bienert 2001; Gebel 2004; Rollefson 1987, 1998; Simmons 2000). These villages were much larger than earlier settlements and were characterized by dense packing of buildings never previously seen (table 21.1). Interestingly, this process of growth was suddenly reversed at the end of the LPPNB. From the terminal LPPNB to the late Pottery Neolithic periods, we see a reduction in the size of settlements and density of architecture (Garfinkel and Miller 2002). Assuming that the scale of architecture and relative population levels were broadly linked, this transition represents a shift from densely packed residential villages to dispersed small hamlets composed of small families.

PRECIPITATION, CLIMATE, AND CULTURAL CHANGE

One of the more persuasive explanations for the abandonment of LPPNB villages is that it was at least partially linked to paleoenvironmental changes. Among others, Rollefson (1996) and Simmons (1997, 2000) have argued that general changes in precipitation and human overexploitation of the local environment around settlements led to the abandonment of settlements. To gauge the possible interconnections it is necessary to look to high-resolution paleoenvironmental research. In doing so, it is not my intent to provide new detailed paleoenvironmental analysis; rather, I focus on existing research results and how they may help us to understand the possible linkages between shifting patterns in climatic, economic, and social systems.

Our understanding of precipitation, temperature, and vegetative changes during the founding

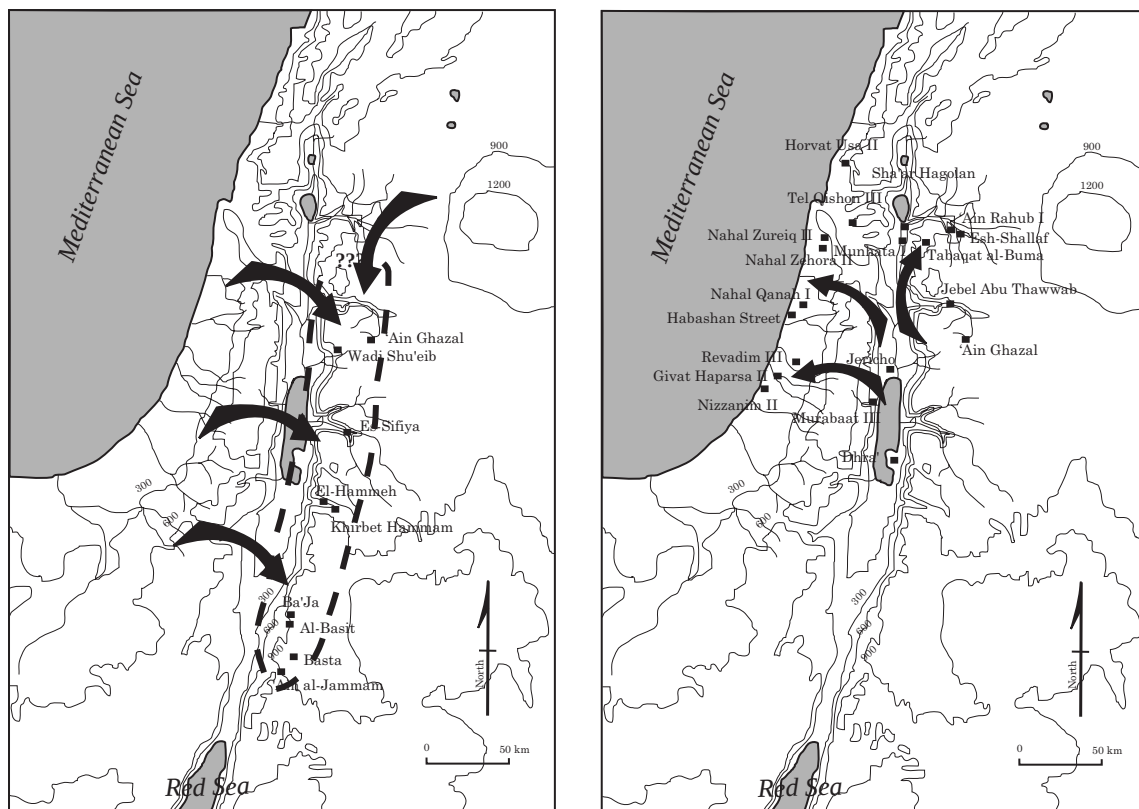


FIGURE 21.1 Population shifts from the Late Pre-Pottery Neolithic B period to the Pottery Neolithic periods. Left, expansion of existing Middle Pre-Pottery Neolithic B period settlements and founding of large Late Pre-Pottery Neolithic B period villages; right, reduction in size or total abandonment of large Pre-Pottery Neolithic B period villages and establishment of new small Pre-Pottery Neolithic C period/Pottery Neolithic A period villages and hamlets.

and abandonment of PPNB and PN villages comes from a range of terrestrial and marine sources. In the case of the southern Levant, the palynology research at Lake Hula (Baruch and Bottema 1991) and study of cave speleotherms (Bar-Matthews, Ayalon, and Kaufman 1997; Bar-Matthews et al. 2003) provide an understanding of vegetation changes, as well as variations in temperature and precipitation. Marine proxies, such as high-resolution marine sediment cores from the eastern Mediterranean (Rohling et al. 2002), provide evidence for striking correlations between events occurring at sea and on land (Bar-Matthews et al. 2003, 3193).

Using alkenone temperature estimates as a proxy of land temperature, Bar-Matthews et al. (2003, 3193) have developed estimates for paleorainfall from 16,000 years ago (kya) to the pre-

sent day. These results indicate that between about 11.5 and 10.5 kya the period that roughly defines the PPNB experienced a significant increase in paleorainfall. From about 10.5 to 9.5 kya, roughly the period of the MPPNB, there was a brief reduction followed by a second major increase in paleorainfall. During the LPPNB, a period defined as lasting from circa 9.5 to 8.7 kya, rainfall varied but was relatively constant over the duration of this cultural phase. It is with the transition from the PPNB to the PN that we see the most dramatic changes. At around 8.7 kya, we see a significant increase in precipitation rapidly followed by a drastic reduction in paleorainfall that lasted to 7.5 kya.

On the basis of their research on climate change in the eastern Mediterranean, Rohling et al. (2002) note that there was a cooling event

TABLE 21.1. *Shifting Settlement, Architectural, and Mortuary Practices through the Pre-Pottery and Pottery Neolithic Periods*

ATTRIBUTE	PPNA	MPPNB	LPNB	PPNC	POTTERY NEOLITHIC
Settlement density	Very low	Low	Very high	Low	Low
Predominant architecture system	Rectangular, single-story free-standing structures	Rectangular, single-story free-standing structures	Rectangular, two-story abutting structures	Rectangular, single-story free-standing structures	Rectangular, single-story buildings, free-standing buildings
Predominant construction practices	Stone foundation, mud and stone walls, mud floors	Stone foundation, stone walls, plaster floors	Stone foundation, stone walls, plaster floors	Stone foundation, mud walls, range of floor treatments	Stone foundation, mud walls, mud floors
Predominant mortuary practices	Single burials, cranial removal, no grave goods	Single burials, cranial removal, rare grave goods	Single burials, no cranial removal, rare grave goods	Multiple burials, no cranial removal, some grave goods	Multiple burials, no cranial removal, some grave goods

NOTE: This table draws upon a range of synthetic studies, such as Banning (1998), Bar-Yosef and Meadow (1995), and Kuijt and Goring-Morris (2002). Focusing on broader patterns, this table outlines the predominant practices for each period. As such, it does not address local settlement level or regional variability.

between 8.6 and 7.9 kya. This correlates with the well-documented 8.2 kya event. Among others, Kobashi et al. (2004) argue that the abrupt climatic change at 8,200 years before present was the most marked of the last 10,000 years. Drawing on the analysis of argon and nitrogen isotopes, they have directly retrieved temperature information illustrating that the magnitude of the temperature change at this time was enormous: a reduction in temperature of $5 \pm 2^\circ\text{C}$ for the decadal average. Disagreements exist as to the length of this event. For example, Leuenberger et al. (1999) argue that climate would have been locked in for sixty years, while Rohling et al. (2002, 44) argue that peak cool conditions “were maintained over a period of 150–250 years, after which more gradual return to warm conditions occurred over a period of several centuries.” Regardless of such disagreements, researchers agree that the 8.2 kya event was abrupt, global, and significant (cf. Edinborough, this volume).

Comparison of paleoclimatic and archaeological data provide insights into the climatic context in which Pre-Pottery Neolithic villages emerged and disappeared. Several points can be made. First, the emergence of MPPN villages is associated with a general increase in precipitation. Such an increase may well have improved growing conditions for specific subsistence plants, creating the foundations for the establishment of smaller villages. Second, and in sharp contrast to this, the appearance of the large “megavillages” of the LPPNB, which presumably reflected significant population growth and aggregation, was not accompanied by climate change; precipitation levels remained relatively constant while these villages expanded. There is at best, therefore, a limited link between precipitation, and presumably therefore resource conditions, and what can be characterized as explosive settlement growth. Finally, the abandonment of these large settlements and the transition between the Pre-Pottery and Pottery Neolithic, in general, fits roughly with the rapid increase followed by a decrease in precipitation mentioned earlier. This certainly supports the argument that paleoclimatic change and precipitation decreases

may have been contributing factors in the abandonment of large aggregated villages.

THE LATE PRE-POTTERY NEOLITHIC: SUBSISTENCE INTENSIFICATION AND SPECIALIZATION

If paleoclimatic change in general, and paleo precipitation in particular, served as an external backdrop for LPPNB population aggregation, rather than as the proximate cause, then how do we explain the rapid growth of large villages? To answer this question, we need to look at them as consequences of local historical developments. As new and unprecedented economic, spatial, and political systems, these villages also represented new residential systems, new ways to live. Once they were established, economic and social competition, such as the control of rituals, would have increased between members of these villages (Kuijt 2001, 2004; Simmons 2000). At some point, control of labor would have become a major factor in the development and maintenance of the villages. To understand the process of nucleation and the founding of villages, it is necessary to consider how this trajectory may have been linked to subsistence specialization and intensification, the development of competing communities, and the need for a shared social foundation to hold these communities together.

One of the critical aspects to the Neolithic revolution is the narrowing of utilized foods and the increased focus on specific plant and animal foods. Harris (1996) notes that there was a remarkable reduction in plant dietary variability from the Natufian period to the LPPNB. At Abu Hurerya, one of the few sites with good data from different periods, there is a reduction from the utilization of 150 plant species in the Natufian to fewer than 10 species by the PPNB (Hillman, Colledge, and Harris 1989; de Moulins 1997). The utilized species in the LPPNB included cereals (einkorn, emmer, and free-threshing wheat, barley, and rye) and herbaceous legumes such as species of *Lens* (lentil), *Pisum* (pea) and *Vicia* (vetch and/or fava bean) (Harris 1996). This reflects a remarkable period

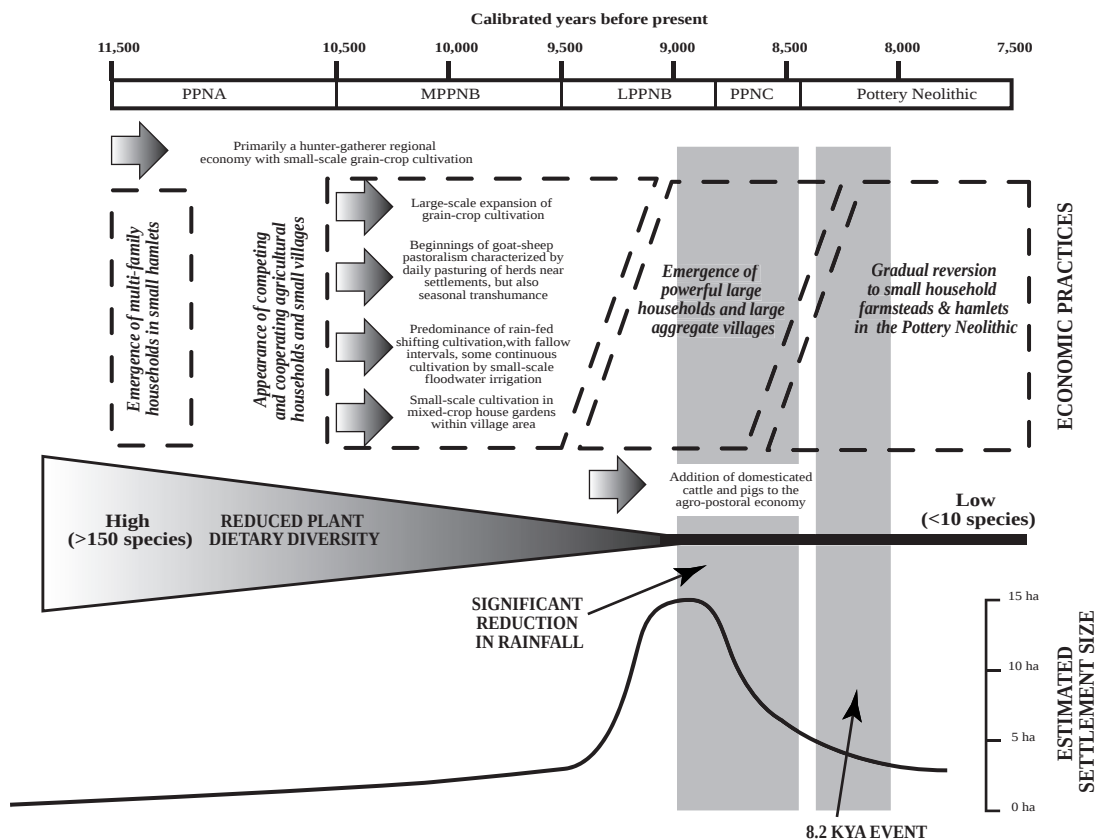


FIGURE 21.2 Emerging cultural and economic practices through the Pre-Pottery and Pottery Neolithic in relation to paleoclimatic change and reduced dietary diversity.

of resource intensification in which we see the deliberate targeting of a restricted number of highly productive food sources (figure 21.2).

Beyond the reduced plant dietary diversity, I suspect that people living in LPPNB communities would have explored a range of methods to increase production of select plants. It is, of course, much easier to document changes in dietary diversity than it is to document the material manifestations of subsistence intensification. Given the lack of archaeological research exploring subsistence intensification in the Near Eastern Neolithic, it is necessary to recognize that such discussions are hypothetical and in need of further study and testing.

As outlined by Tainter (2006, 4.3), intensification can be defined as an increase in the inputs to a productive system to obtain higher

gross outputs. Given that the environmental potential for agriculture is limited, past human communities often explored technological and social means to maximize production from food resources. This includes manipulation of the growing environment for plants and animals, using new or different extractive technologies. Tainter (2006, 4.1) neatly sums this up: "It is usually possible to coax more resource production by applying capital and technology, increasing labor, applying energy subsidies, and making production more knowledge-intensive. Irrigation, fertilization, and mechanization are all ways to increase production, as is putting in more hours or tilling more land." Such attempts are, of course, limited by environmental potential and variability; intensification cannot continue indefinitely.

Presumably one of the original factors in the location of MPPNB villages was access to good water resources and proximity to good field areas for growing crops. I think that the increase in the size and density of MPPNB and LPPNB settlements was linked to increased seasonal labor needs for planting, protecting crops, processing foods, storing, and, ultimately, protecting food resources from other communities. Increased labor would also have been required for maintaining field areas, weeding, watering at select times of the year, and managing crops. People may have moved into villages as smaller regional hamlets failed, possibly viewing this as a form of subsistence risk minimization.

Although it is difficult to demonstrate with archaeological data, I believe that it is entirely likely that the reason(s) for population aggregation included the creation and maintenance of larger social communities, initially focused on household-based subsistence organization (see Kuijt and Goring-Morris 2002; Kuijt 2001 for more detailed discussion of this). However, while there are some advantages to increased scale and control of labor, such as greater agricultural production, it comes with a significant negative by-product: the movement of people away from more remote field systems, and the greater transportation costs of moving goods and people between field and residential or storage locations. Thus, in many ways, nucleated villages do not make sense on the basis of economic modeling alone. While largely beyond the scope of this chapter, it is possible that they were founded for social reasons that were distinct, and in some ways in opposition to, economic and subsistence considerations. The reasons for aggregation, therefore, are likely to have been multicausal and included interest in improving control and predictability of food resources, perceived protection from members of other communities, and ritual that served as a form of social glue that connected people and held villages together in the face of changing social, economic, and cultural practices. In sum, it is likely that people

were both drawn and forced into large LPPNB towns/villages.

VILLAGE ABANDONMENT AND REDUCED CARRYING CAPACITY AND SOCIOPOLITICAL SIMPLIFICATION

How, then, are we to explain the abandonment of LPPNB villages? Given the number of people living in LPPNB communities, and the subsistence focus on select plant species that required specific moisture levels and soil conditions, it can be argued that by the LPPNB people became “locked into” an agropastoralist economy. People who practice intensive agricultural systems often minimize seasonal or yearly shortages by relying on stored food produced by a small number of highly productive crops (Harris 2002). Subsistence intensification on this scale results in a cascading number of tasks related to the planting, maintenance, and protection of the crops, and ultimately residency of people around their plants. Once they became relatively sedentary, the majority of families did not have the option of changing their overall subsistence systems or of rapidly diversifying their subsistence base. While some families, or members of such families, might have reverted to a more mobile gathering-pastoralist lifestyle, this option is unlikely to have been feasible to everyone. Occurring over several hundred years, this transition would have been a gradual process, with people occasionally reverting back to increased use of wild resources.

Rather than focusing on a single-cause explanation, I think it is profitable to conceptualize the abandonment of Neolithic villages as reflecting a cultural and economic tipping point where increased population growth, precipitation decreases, ecological degradation, and reduced carrying capacity (cf. Hayden 1981) acted on the new economic and social trajectories that had emerged earlier in the PPNB, corresponding to the pruning or decimation phase in Prentiss and Chatters’s (2003) macroevolutionary model. As noted earlier, the early LPPNB witnesses an increase in rainfall, and the later stages were characterized by relatively stable rainfall levels.

Research by Bar-Matthews et al. (2003) described earlier illustrates significant variation in paleorainfall during the PPNC and Pottery Neolithic, with an observable increase spike and then significant reduction in precipitation at the start of the early Pottery Neolithic period. One possible by-product of a general reduction in precipitation would have been a more spatially restricted woodland and range area in the Levant. It may have also resulted in a reduction in the predictability, scale, and density of local food resources. Increased aridity in ecotone areas and increased constriction of vegetation into upland areas with greater precipitation would have also altered the economic viability of living in communities situated in peripheral environmental areas.

Human overexploitation of the local environment probably also accentuated the impact of changing climatic conditions on Neolithic communities (readers are directed to Köhler-Rollefson and Rollefson 1990; Rollefson and Köhler-Rollefson 1989; Rollefson 1996, 2004 for more detailed considerations of these topics). Rollefson (1996) argues that building activities in the Middle Pre-Pottery Neolithic B period would have brought about local deforestation for cooking fuel and heating. Over time, and with increased frequency, this would have scoured the areas immediately around settlements. The much larger settlements of the Late Pre-Pottery Neolithic B, some of which were two to three times larger than earlier MPPNB settlements, likely had an even greater impact on the areas around settlements. Supporting these large and densely populated settlements would have required increased exploitation of forests for firewood and building material, a reduction in the wild animal food resources living near settlements, and increased soil erosion due to agricultural and overgrazing. This may have made it more difficult to rebuild houses and limited the amount of firewood available.

REDUCED CARRYING CAPACITY AND VILLAGE ABANDONMENT

The combination of degrading climatic, resource, and demographic conditions would

have made it increasingly difficult for people to continue to live in large aggregate LPPNB, PPNC, and Pottery Neolithic villages at high-density levels (Kuijt 2000; Simmons 2000). Depending on their location, some villages would have been abandoned (e.g., Basta, which was located along the desert ecotone), while other villages located near good water sources would have been maintained. The remaining viable option for people in smaller villages centered on families identifying new potential farming areas, to reestablish their farms in these areas and at a population density that could be supported by the local catchment. In some ways, then, the record of human adaptation and potential for people to live in high-density contexts was dictated by the structure of subsistence resources.

Rollefson (1996) and Simmons (2000) note that with environmental changes traditional field areas may have become less productive, less likely to receive predictable rain to start seed germination, and more difficult to manage as groundwater sources became less reliable. Overgrazing would have also resulted in soil erosion (Rollefson 1996). Thus, despite attempts to intensify agricultural production, communities probably faced reduced crop yields around settlements, resulting in reduced carrying capacity. This would have encouraged, if not pushed, farmers to establish new and more distant field areas closer to water sources or in better upland locations during the LPPNB. To farm new areas, or to practice hunting in new locations, would have required people to spend more time away from their home village. Collectively this may have gradually reduced the viability of mega-settlements, creating an evolutionary tipping point if you will, where there was an irreversible compounding of factors leading to abandonment.

SIMPLIFICATION AS AN ALTERNATIVE TO INTENSIFICATION?

In the long term, intensive agropastoralism became the foundation for many, if not most, later societies. Surprisingly, the socially complex

aggregate villages of the Pre-Pottery Neolithic did not immediately carry forward into the Pottery Neolithic: people were not able to develop mechanisms to overcome the social problems linked to the increased scale of villages and subsistence intensification, nor were they able to develop other economic practices to overcome reduced environmental conditions. Pottery Neolithic people did not move toward further subsistence intensification; rather, the trend was one of social and political simplification with people engaged in smaller-scale communities and more mobile ways of life.

While further research is needed, it can be argued that LPPNB social organization was based on the household as a social and economic unit (Kuijt 2001; Rollefson 2004; Simmons 2000). The coexistence of multiple households and families within these villages must have required a balancing of competition and cooperation between and within households. As I have argued elsewhere (Kuijt 2001), one possible reason for the breakdown of this system, exemplified by the dispersal of people and the abandonment of villages, is that existing social systems were not able to deal with the changing scale of communities or with the emergence of new forms of social differentiation. Rather than expanding their social systems, it appears that people after the LPPNB moved toward smaller-scale social units focused on the household level.

Thus, sociopolitical simplification, such as the appearance of smaller-scale social households as opposed to community units, and the associated gradual dispersal of people out of larger residential communities, may have served as one social solution to continued reduced carrying capacity, population growth in the LPPNB, and climatic change in the Neolithic. Doubtless, the end result of this process was not intended, and community and households members were not aware of its long-term consequences. Rather, the shifts described earlier were the result of short-term decision making that led to long-term evolutionary changes.

“NEOLITHIC DEVOLUTION” AND THE TRANSITION TO THE POTTERY NEOLITHIC

Regional research by a number of authors (e.g., Banning 1995, 2004; Banning, Rahimi, and Siggers 1994; Simmons 1997, 2000; Rollefson 1998) illustrates that there is general occupational and economic continuity in the southern Levant between the Pre-Pottery and Pottery Neolithic. While people generally lived in smaller settlements, they continued, with local variation, to rely on an agropastoralist economic focus. At the same time, it can be argued, the transition between the Pre-Pottery and Pottery Neolithic was both rapid and, in many ways, reflects the adoption of what can, for lack of a better term, be described as simplification and downscaling. The general trajectory of economic continuity, albeit on a smaller scale, occurred within the framework of decreased sociopolitical complexity and population dispersal. The decentralization of social systems, manifested through the dispersal of people from large villages to smaller hamlets, highlights a movement toward sociopolitical simplification. In general, less people lived in villages (villages to hamlets) and smaller-scale settlements. From an archaeological standpoint, this pattern appears to be quite stark, so much so that Rollefson (1998) refers to this as “Neolithic Devolution.” While further research is necessary to determine how this term should be defined and applied in this case, the phrase “Neolithic Devolution” does intuitively capture the change in character and tempo of the Pre-Pottery to Pottery Neolithic transition.

It also raises an important question. If LPPNB ways of life, evolved as a result of population aggregation due to demographic increases, subsistence intensification, increased centralization of labor, the development of powerful houses through kin and economic units, and the development of regional economic and ritual centers, then why do we not see the emergence of some form of centralized leadership? On the basis of analogies with other cultures,

researchers could understandably expect that with food production and population aggregation in regional centers, we would find the social context in which certain individuals consolidated power and authority within the Neolithic communities. In the minds of some researchers, population growth though the MPPNB and LPPNB, possible political centralization in certain large regional settlements in the LPPNB, and greater reliance on intensive agriculture and stored foods should have established the evolutionary conditions for enormous increases in social segmentation, perhaps even with the development of a clear, and firmly entrenched, hierarchical division of authority and power.

Paradoxically, the material evidence suggests a very different story. If anything, available archaeological data for approximately 1,500 years of the MPPNB and LPPNB provide only limited evidence for emerging social inequality in the face of increased population growth, economic intensification, and emerging large villages (see Kuijt 2001). While there is some evidence for increased social segmentation after this point, with our best data probably being an increased frequency of grave goods, the size of residential communities falls drastically.

One possible explanation for this pattern is that internal social competition within these villages limited the ability of people to consolidate power. If LPPNB aggregate village communities were organized along lineage lines, then competition between them for power and authority could have prevented the consolidation of authority by a single lineage and its representatives. New means of organizing positions of leadership do not seem to have emerged out of the rapid changes in economic systems, deteriorating environmental conditions, and the almost exponential aggregation of people into communities described here. Instead, after nearly 1,500 years of intensification of subsistence resources, large aggregate Neolithic villages were abandoned with new household scale farmsteads and hamlets appearing. This is only surprising if one takes for granted the

traditional neoevolutionary view that successive increases in complexity follow on from one another more or less automatically in the face of new adaptive challenges. On the contrary, whereas successful technical innovation may be more or less immediately perceptible to the people concerned, innovations in social institutions may have far less predictable consequences, as well as being potentially detrimental to existing social interests

Thus, while climate and ecology may have destabilized Late Pre-Pottery Neolithic B communities, the evolution and abandonment of Neolithic aggregate village system must be understood from a broader perspective of the intersection of social relationships and short-term decision making at the scale of the household or lineage. Consideration of macroscale evolutionary patterns and the appearance of new resource management systems characterized by a trajectory of diversification and decimation (Prentiss and Chatters 2003) remind evolutionary researchers that only archaeology can address select goals and evolutionary patterns. Explaining those patterns, however, returns us to the microscale of analyzing day-to-day processes and the internal and external factors that affected them in Pre-Pottery and Pottery Neolithic villages.

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LIST OF CONTRIBUTORS

Stephen Shennan

*Institute of Archaeology
University College London*

Robert Auger

*London School of Hygiene and
Tropical Medicine*

Jacob Bartruff

*Department of Geography
University of Oregon*

Michael F. Charlton

*4439 Wimbeldon Way, Kalamazoo,
MI 49009*

Stanca Ciupe

Santa Fe Institute, Santa Fe

Ethan E. Cochrane

*Institute of Archaeology
University College London*

Sarah Cole

*Department of Anthropology
Washington State University*

Mark Collard

*Department of Archaeology
Simon Fraser University*

R. I. M. Dunbar

*Institute of Cognitive and Evolutionary
Anthropology
University of Oxford*

Kevan Edinborough

*Department of Archaeology
Simon Fraser University*

Jon M. Erlandson

*Department of Anthropology
University of Oregon*

Ben Fitzhugh

*Department of Anthropology
University of Washington, Seattle*

Laura Fortunato

*Department of Anthropology
University College London*

Robert Hosfield

*Department of Archaeology
University of Reading*

John Hughes

*School of Geographical Sciences
University of Bristol*

Peter Jordan

*Department of Archaeology
University of Aberdeen*

Douglas J. Kennett

*Department of Anthropology
University of Oregon*

Timothy A. Kohler

*Department of Anthropology
Washington State University*

Ian Kuijt

*Department of Anthropology
University of Notre Dame*

Mark W. Lake

*Institute of Archaeology
University College London*

Ruth Mace

*Department of Anthropology
University College London*

Alex Mesoudi

*School of Biological and Chemical Sciences
Queen Mary, University of London*

Steven Mithen

*School of Human and Environmental Science
University of Reading*

Michael J. O'Brien

*Department of Anthropology
University of Missouri, Columbia*

Aimée Plourde

*Institute of Archaeology
University College London*

Felix Riede

*Institute of Archaeology
University College London*

Sam Smith

*School of Human and Environmental Science
University of Reading*

James Steele

*Institute of Archaeology
University College London*

Jamshid J. Tehrani

*Department of Anthropology
University of Durham*

Jay Venti

*MediaZone.com Inc.
San Carlos, CA*

Polly Wiessner

*Department of Anthropology
University of Utah*

Bruce Winterhalder

*Department of Anthropology
University of California, Davis*

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